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Contents at a Glance

Part I  The Java Language
1  The History and Evolution of Java
2  An Overview of Java
3  Data Types, Variables, and Arrays
4  Operators
5  Control Statements
6  Introducing Classes
7  A Closer Look at Methods and Classes
8  Inheritance
9  Packages and Interfaces
10  Exception Handling
11  Multithreaded Programming
12  Enumerations, Autoboxing, and Annotations
13  I/O, Try-with-Resources, and Other Topics
14  Generics
15  Lambda Expressions
16  Modules

Part II  The Java Library
17  String Handling
18  Exploring java.lang
19  java.util Part 1: The Collections Framework
20  java.util Part 2: More Utility Classes
21  Input/Output: Exploring java.io
22  Exploring NIO
23  Networking
24 Event Handling
25 Introducing the AWT: Working with Windows, Graphics, and Text
26 Using AWT Controls, Layout Managers, and Menus
27 Images
28 The Concurrency Utilities
29 The Stream API
30 Regular Expressions and Other Packages

Part III  Introducing GUI Programming with Swing
31 Introducing Swing
32 Exploring Swing
33 Introducing Swing Menus

Part IV  Introducing GUI Programming with JavaFX
34 Introducing JavaFX GUI Programming
35 Exploring JavaFX Controls
36 Introducing JavaFX Menus

Part V   Applying Java
37 Java Beans
38 Introducing Servlets

Part VI  Appendixes
A Using Java’s Documentation Comments
B An Overview of Java Web Start
C Introducing JShell
D Applet Basics

Index
Contents

Preface

Part I  The Java Language

Chapter 1  The History and Evolution of Java
  Java’s Lineage
    The Birth of Modern Programming: C
    C++: The Next Step
    The Stage Is Set for Java
  The Creation of Java
    The C# Connection
  How Java Impacted the Internet
    Java Applets
    Security
    Portability
  Java’s Magic: The Bytecode
  Moving Beyond Applets
  Servlets: Java on the Server Side
  The Java Buzzwords
    Simple
    Object-Oriented
    Robust
    Multithreaded
    Architecture-Neutral
    Interpreted and High Performance
    Distributed
    Dynamic
The Evolution of Java
Java SE 9
A Culture of Innovation

Chapter 2  An Overview of Java
Object-Oriented Programming
  Two Paradigms
  Abstraction
  The Three OOP Principles
A First Simple Program
  Entering the Program
  Compiling the Program
  A Closer Look at the First Sample Program
A Second Short Program
Two Control Statements
  The if Statement
  The for Loop
Using Blocks of Code
Lexical Issues
  Whitespace
  Identifiers
  Literals
  Comments
  Separators
  The Java Keywords
The Java Class Libraries

Chapter 3  Data Types, Variables, and Arrays
Java Is a Strongly Typed Language
The Primitive Types
Integers
  byte
  short
  int
  long
Floating-Point Types
  float
  double
Characters
Booleans
A Closer Look at Literals
   Integer Literals
   Floating-Point Literals
   Boolean Literals
   Character Literals
   String Literals
Variables
   Declaring a Variable
   Dynamic Initialization
   The Scope and Lifetime of Variables
Type Conversion and Casting
   Java’s Automatic Conversions
   Casting Incompatible Types
Automatic Type Promotion in Expressions
   The Type Promotion Rules
Arrays
   One-Dimensional Arrays
   Multidimensional Arrays
   Alternative Array Declaration Syntax
A Few Words About Strings

Chapter 4 Operators
Arithmetic Operators
   The Basic Arithmetic Operators
   The Modulus Operator
   Arithmetic Compound Assignment Operators
   Increment and Decrement
The Bitwise Operators
   The Bitwise Logical Operators
   The Left Shift
   The Right Shift
   The Unsigned Right Shift
   Bitwise Operator Compound Assignments
Relational Operators
Boolean Logical Operators
Short-Circuit Logical Operators
The Assignment Operator
The ? Operator
Operator Precedence
Using Parentheses

Chapter 5  Control Statements
Java’s Selection Statements
  if
  switch
Iteration Statements
  while
  do-while
  for
  The For-Each Version of the for Loop
Nested Loops
Jump Statements
  Using break
  Using continue

Chapter 6  Introducing Classes
Class Fundamentals
  The General Form of a Class
  A Simple Class
Declaring Objects
  A Closer Look at new
Assigning Object Reference Variables
Introducing Methods
  Adding a Method to the Box Class
  Returning a Value
  Adding a Method That Takes Parameters
Constructors
  Parameterized Constructors
The this Keyword
  Instance Variable Hiding
Garbage Collection
A Stack Class

Chapter 7  A Closer Look at Methods and Classes
Chapter 8   Inheritance

Inheritance Basics
  Member Access and Inheritance
  A More Practical Example
  A Superclass Variable Can Reference a Subclass Object
Using super
  Using super to Call Superclass Constructors
  A Second Use for super
Creating a Multilevel Hierarchy
When Constructors Are Executed
Method Overriding
Dynamic Method Dispatch
  Why Overridden Methods?
  Applying Method Overriding
Using Abstract Classes
Using final with Inheritance
  Using final to Prevent Overriding
  Using final to Prevent Inheritance
The Object Class

Chapter 9   Packages and Interfaces
Packages
   Defining a Package
   Finding Packages and CLASSPATH
   A Short Package Example
Packages and Member Access
   An Access Example
Importing Packages
Interfaces
   Defining an Interface
   Implementing Interfaces
   Nested Interfaces
   Applying Interfaces
   Variables in Interfaces
   Interfaces Can Be Extended
Default Interface Methods
   Default Method Fundamentals
   A More Practical Example
   Multiple Inheritance Issues
Use static Methods in an Interface
Private Interface Methods
Final Thoughts on Packages and Interfaces

Chapter 10 Exception Handling
   Exception-Handling Fundamentals
   Exception Types
   Uncaught Exceptions
   Using try and catch
      Displaying a Description of an Exception
   Multiple catch Clauses
   Nested try Statements
   throw
   throws
   finally
Java’s Built-in Exceptions
Creating Your Own Exception Subclasses
Chained Exceptions
Three Additional Exception Features
Chapter 11  Multithreaded Programming

The Java Thread Model
  Thread Priorities
  Synchronization
  Messaging
  The Thread Class and the Runnable Interface

The Main Thread
Creating a Thread
  Implementing Runnable
  Extending Thread
  Choosing an Approach
Creating Multiple Threads
Using isAlive( ) and join( )

Thread Priorities
Synchronization
  Using Synchronized Methods
  The synchronized Statement
Interthread Communication
  Deadlock
SUSpending, Resuming, and Stopping Threads
Obtaining a Thread’s State
Using a Factory Method to Create and Start a Thread
Using Multithreading

Chapter 12  Enumerations, Autoboxing, and Annotations

Enumerations
  Enumeration Fundamentals
  The values( ) and valueOf( ) Methods
  Java Enumerations Are Class Types
  Enumerations Inherit Enum
  Another Enumeration Example

Type Wrappers
  Character
  Boolean
  The Numeric Type Wrappers

Autoboxing
Autoboxing and Methods
Autoboxing/Unboxing Occurs in Expressions
Autoboxing/Unboxing Boolean and Character Values
Autoboxing/Unboxing Helps Prevent Errors
A Word of Warning

Annotations
Annotation Basics
Specifying a Retention Policy
Obtaining Annotations at Run Time by Use of Reflection
The AnnotatedElement Interface
Using Default Values
Marker Annotations
Single-Member Annotations
The Built-In Annotations

Type Annotations
Repeating Annotations
Some Restrictions

Chapter 13 I/O, Try-with-Resources, and Other Topics
I/O Basics
Streams
Byte Streams and Character Streams
The Predefined Streams
Reading Console Input
Reading Characters
Reading Strings
Writing Console Output
The PrintWriter Class
Reading and Writing Files
Automatically Closing a File
The transient and volatile Modifiers
Using instanceof
strictfp
Native Methods
Using assert
Assertion Enabling and Disabling Options
Static Import
Chapter 14  Generics
  What Are Generics?
  A Simple Generics Example
    Generics Work Only with Reference Types
    Generic Types Differ Based on Their Type Arguments
    How Generics Improve Type Safety
  A Generic Class with Two Type Parameters
  The General Form of a Generic Class
  Bounded Types
  Using Wildcard Arguments
    Bounded Wildcards
  Creating a Generic Method
    Generic Constructors
  Generic Interfaces
  Raw Types and Legacy Code
  Generic Class Hierarchies
    Using a Generic Superclass
    A Generic Subclass
  Run-Time Type Comparisons Within a Generic Hierarchy
    Casting
    Overriding Methods in a Generic Class
  Type Inference with Generics
  Erasure
    Bridge Methods
  Ambiguity Errors
Some Generic Restrictions
  Type Parameters Can’t Be Instantiated
  Restrictions on Static Members
  Generic Array Restrictions
  Generic Exception Restriction

Chapter 15  Lambda Expressions
  Introducing Lambda Expressions
    Lambda Expression Fundamentals
    Functional Interfaces
Chapter 16  Modules

Module Basics
   A Simple Module Example
   Compile and Run the First Module Example
   A Closer Look at requires and exports
java.base and the Platform Modules
Legacy Code and the Unnamed Module
Exporting to a Specific Module
Using requires transitive
Use Services
   Service and Service Provider Basics
   The Service-Based Keywords
   A Module-Based Service Example
Module Graphs
Three Specialized Module Features
   Open Modules
   The opens Statement
   requires static
Introducing jlink and Module JAR Files
   Linking Files in an Exploded Directory
   Linking Modular JAR Files
   JMOD Files
A Brief Word About Layers and Automatic Modules
Final Thoughts on Modules
Part II  The Java Library

Chapter 17  String Handling

The String Constructors
String Length
Special String Operations
  String Literals
  String Concatenation
  String Concatenation with Other Data Types
  String Conversion and toString()
Character Extraction
  charAt()
  getChars()
  getBytes()
  toCharArray()
String Comparison
  equals() and equalsIgnoreCase()
  regionMatches()
  startsWith() and endsWith()
  equals() Versus ==
  compareTo()
Searching Strings
Modifying a String
  substring()
  concat()
  replace()
  trim()
Data Conversion Using valueOf()
Changing the Case of Characters Within a String
Joining Strings
Additional String Methods
StringBuffer
  StringBuffer Constructors
  length() and capacity()
  ensureCapacity()
  setLength()
  charAt() and setCharAt()
getChars( )
append( )
insert( )
reverse( )
delete( ) and deleteCharAt( )
replace( )
substring( )
Additional StringBuffer Methods
StringBuilder
Chapter 18 Exploring java.lang
Primitive Type Wrappers
Number
Double and Float
Understanding isInfinite( ) and isNaN( )
Byte, Short, Integer, and Long
Character
Additions to Character for Unicode Code Point Support
Boolean
Void
Process
Runtime
Memory Management
Executing Other Programs
Runtime.Version
ProcessBuilder
System
Using currentTimeMillis( ) to Time Program Execution
Using arraycopy( )
Environment Properties
System.Logger and System.LoggerFinder
Object
Using clone( ) and the Cloneable Interface
Class
ClassLoader
Math
Trigonometric Functions
Exponential Functions
Rounding Functions
Miscellaneous Math Methods
StrictMath
Compiler
Thread, ThreadGroup, and Runnable
The Runnable Interface
Thread
ThreadGroup
ThreadLocal and InheritableThreadLocal
Package
Module
ModuleLayer
RuntimePermission
Throwable
SecurityManager
StackTraceElement
StackWalker and StackWalker.StackFrame
Enum
ClassValue
The CharSequence Interface
The Comparable Interface
The Appendable Interface
The Iterable Interface
The Readable Interface
The AutoCloseable Interface
The Thread.UncaughtExceptionHandler Interface
The java.lang Subpackages
  java.lang.annotation
  java.lang.instrument
  java.lang.invoke
  java.lang.module
  java.lang.management
  java.lang.ref
  java.lang.reflect

Chapter 19  java.util Part 1: The Collections Framework
Collections Overview
The Collection Interfaces
  The Collection Interface
  The List Interface
  The Set Interface
  The SortedSet Interface
  The NavigableSet Interface
  The Queue Interface
  The Deque Interface
The Collection Classes
  The ArrayList Class
  The LinkedList Class
  The HashSet Class
  The LinkedHashSet Class
  The TreeSet Class
  The PriorityQueue Class
  The ArrayDeque Class
  The EnumSet Class
Accessing a Collection via an Iterator
  Using an Iterator
  The For-Each Alternative to Iterators
Spliterators
Storing User-Defined Classes in Collections
The RandomAccess Interface
Working with Maps
  The Map Interfaces
  The Map Classes
Comparators
  Using a Comparator
The Collection Algorithms
Arrays
The Legacy Classes and Interfaces
  The Enumeration Interface
  Vector
  Stack
  Dictionary
  Hashtable
Properties
Using store( ) and load( )
Parting Thoughts on Collections

Chapter 20  java.util Part 2: More Utility Classes
StringTokenizer
BitSet
Optional, OptionalDouble, OptionalInt, and OptionalLong
Date
Calendar
GregorianCalendar
TimeZone
SimpleTimeZone
Locale
Random
Timer and TimerTask
Currency
Formatter
The Formatter Constructors
The Formatter Methods
Formatting Basics
Formatting Strings and Characters
Formatting Numbers
Formatting Time and Date
The %n and %% Specifiers
Specifying a Minimum Field Width
Specifying Precision
Using the Format Flags
Justifying Output
The Space, +, 0, and ( Flags
The Comma Flag
The # Flag
The Uppercase Option
Using an Argument Index
Closing a Formatter
The Java printf( ) Connection
Scanner
Chapter 21  Input/Output: Exploring java.io

The I/O Classes and Interfaces

File
  Directories
  Using FilenameFilter
  The listFiles() Alternative
  Creating Directories

The AutoCloseable, Closeable, and Flushable Interfaces

I/O Exceptions

Two Ways to Close a Stream

The Stream Classes

The Byte Streams
  InputStream
  OutputStream
  FileInputStream
  FileOutputStream
  ByteArrayInputStream
ByteArrayOutputStream
Filtered Byte Streams
Buffered Byte Streams
SequenceInputStream
PrintStream
DataOutputStream and DataInputStream
RandomAccessFile

The Character Streams
Reader
Writer
FileReader
FileWriter
CharArrayReader
CharArrayWriter
BufferedReader
BufferedWriter
PushbackReader
PrintWriter

The Console Class

Serialization
Serializable
Externalizable
ObjectOutput
ObjectOutputStream
ObjectInput
ObjectInputStream

A Serialization Example

Stream Benefits

Chapter 22 Exploring NIO

The NIO Classes

NIO Fundamentals
Buffers
Channels
Charsets and Selectors
Enhancements Added by NIO.2
The Path Interface
Chapter 23  Networking
Networking Basics
The Networking Classes and Interfaces
InetAddress
   Factory Methods
   Instance Methods
Inet4Address and Inet6Address
TCP/IP Client Sockets
URL
URLConnection
HttpURLConnection
The URI Class
Cookies
TCP/IP Server Sockets
Datagrams
   DatagramSocket
   DatagramPacket
   A Datagram Example

Chapter 24  Event Handling
Two Event Handling Mechanisms
The Delegation Event Model
   Events
   Event Sources
   Event Listeners
Event Classes
   The ActionEvent Class
   The AdjustmentEvent Class
   The ComponentEvent Class
The ContainerEvent Class
The FocusEvent Class
The InputEvent Class
The ItemEvent Class
The KeyEvent Class
The MouseEvent Class
The MouseWheelEvent Class
The TextEvent Class
The WindowEvent Class

Sources of Events
Event Listener Interfaces
  The ActionListener Interface
  The AdjustmentListener Interface
  The ComponentListener Interface
  The ContainerListener Interface
  The FocusListener Interface
  The ItemListener Interface
  The KeyListener Interface
  The MouseListener Interface
  The MouseMotionListener Interface
  The MouseWheelListener Interface
  The TextListener Interface
  The WindowFocusListener Interface
  The WindowListener Interface

Using the Delegation Event Model
  Some Key AWT GUI Concepts
  Handling Mouse Events
  Handling Keyboard Events

Adapter Classes
Inner Classes
  Anonymous Inner Classes

Chapter 25  Introducing the AWT: Working with Windows, Graphics, and Text
  AWT Classes
  Window Fundamentals
    Component
Container
Panel
Window
Frame
Canvas

Working with Frame Windows
  Setting the Window’s Dimensions
  Hiding and Showing a Window
  Setting a Window’s Title
  Closing a Frame Window
  The paint( ) Method
  Displaying a String
  Setting the Foreground and Background Colors
  Requesting Repainting
  Creating a Frame-Based Application

Introducing Graphics
  Drawing Lines
  Drawing Rectangles
  Drawing Ellipses and Circles
  Drawing Arcs
  Drawing Polygons
  Demonstrating the Drawing Methods
  Sizing Graphics

Working with Color
  Color Methods
  Setting the Current Graphics Color
  A Color Demonstration Program

Setting the Paint Mode

Working with Fonts
  Determining the Available Fonts
  Creating and Selecting a Font
  Obtaining Font Information

Managing Text Output Using FontMetrics

Chapter 26   Using AWT Controls, Layout Managers, and Menus

AWT Control Fundamentals
  Adding and Removing Controls
Chapter 27  Images

File Formats
Image Fundamentals: Creating, Loading, and Displaying
  Creating an Image Object
  Loading an Image
  Displaying an Image
Double Buffering
ImageProducer
  MemoryImageSource
ImageConsumer
    PixelGrabber
ImageFilter
    CropImageFilter
    RGBImageFilter
Additional Imaging Classes

Chapter 28   The Concurrency Utilities
The Concurrent API Packages
    java.util.concurrent
    java.util.concurrent.atomic
    java.util.concurrent.locks
Using Synchronization Objects
    Semaphore
    CountDownLatch
    CyclicBarrier
    Exchanger
    Phaser
Using an Executor
    A Simple Executor Example
    Using Callable and Future
The TimeUnit Enumeration
The Concurrent Collections
Locks
Atomic Operations
Parallel Programming via the Fork/Join Framework
    The Main Fork/Join Classes
    The Divide-and-Conquer Strategy
    A Simple First Fork/Join Example
Understanding the Impact of the Level of Parallelism
    An Example that Uses RecursiveTask<V>
Executing a Task Asynchronously
Cancelling a Task
Determining a Task’s Completion Status
Restarting a Task
Things to Explore
Some Fork/Join Tips
The Concurrency Utilities Versus Java’s Traditional Approach

Chapter 29   The Stream API

Stream Basics
Stream Interfaces
How to Obtain a Stream
A Simple Stream Example
Reduction Operations
Using Parallel Streams
Mapping
Collecting
Iterators and Streams
Use an Iterator with a Stream
Use Spliterator
More to Explore in the Stream API

Chapter 30   Regular Expressions and Other Packages

Regular Expression Processing
Pattern
Matcher
Regular Expression Syntax
Demonstrating Pattern Matching
Two Pattern-Matching Options
Exploring Regular Expressions
Reflection
Remote Method Invocation (RMI)
A Simple Client/Server Application Using RMI
Formatting Date and Time with java.text
DateFormat Class
SimpleDateFormat Class
The java.time Time and Date API
Time and Date Fundamentals
Formatting Date and Time
Parsing Date and Time Strings
Other Things to Explore in java.time

Part III   Introducing GUI Programming with Swing

Chapter 31   Introducing Swing
The Origins of Swing
Swing Is Built on the AWT
Two Key Swing Features
  Swing Components Are Lightweight
  Swing Supports a Pluggable Look and Feel
The MVC Connection
Components and Containers
  Components
  Containers
    The Top-Level Container Panes
The Swing Packages
A Simple Swing Application
Event Handling
Painting in Swing
  Painting Fundamentals
    Compute the Paintable Area
    A Paint Example

Chapter 32  Exploring Swing
  JLabel and ImageIcon
  JTextField
  The Swing Buttons
    JButton
    JToggleButton
  Check Boxes
  Radio Buttons
  JTabbedPane
  JScrollPane
  JList
  JComboBox
  Trees
  JTable

Chapter 33  Introducing Swing Menus
  Menu Basics
  An Overview of JMenuBar, JMenu, and JMenuItem
    JMenuBar
    JMenu
JMenuItem
Create a Main Menu
Add Mnemonics and Accelerators to Menu Items
Add Images and Tooltips to Menu Items
Use JRadioButtonMenuItem and JCheckBoxMenuItem
Create a Popup Menu
Create a Toolbar
Use Actions
Put the Entire MenuDemo Program Together
Continuing Your Exploration of Swing

Part IV  Introducing GUI Programming with JavaFX

Chapter 34  Introducing JavaFX GUI Programming
JavaFX Basic Concepts
  The JavaFX Packages
  The Stage and Scene Classes
  Nodes and Scene Graphs
Layouts
  The Application Class and the Life-cycle Methods
Launching a JavaFX Application
A JavaFX Application Skeleton
Compiling and Running a JavaFX Program
The Application Thread
A Simple JavaFX Control: Label
Using Buttons and Events
  Event Basics
  Introducing the Button Control
  Demonstrating Event Handling and the Button
Drawing Directly on a Canvas

Chapter 35  Exploring JavaFX Controls
Using Image and ImageView
  Adding an Image to a Label
  Using an Image with a Button
ToggleButton
RadioButton
  Handling Change Events in a Toggle Group
An Alternative Way to Handle Radio Buttons

CheckBox
ListView
  ListView Scroll Bars
  Enabling Multiple Selections
ComboBox
TextField
ScrollPane
TreeView
Introducing Effects and Transforms
  Effects
  Transforms
  Demonstrating Effects and Transforms
Adding Tooltips
Disabling a Control

Chapter 36  Introducing JavaFX Menus

Menu Basics
An Overview of MenuBar, Menu, and MenuItem
  MenuBar
  Menu
  MenuItem
Create a Main Menu
Add Mnemonics and Accelerators to Menu Items
Add Images to Menu Items
Use RadioMenuItem and CheckMenuItem
Create a Context Menu
Create a Toolbar
Put the Entire MenuDemo Program Together
Continuing Your Exploration of JavaFX

Part V  Applying Java

Chapter 37  Java Beans

What Is a Java Bean?
Advantages of Java Beans
Introspection
  Design Patterns for Properties
Design Patterns for Events
Methods and Design Patterns
Using the BeanInfo Interface
Bound and Constrained Properties
Persistence
Customizers
The Java Beans API
   Introspector
   PropertyDescriptor
   EventSetDescriptor
   MethodDescriptor
A Bean Example

Chapter 38  Introducing Servlets

Background
The Life Cycle of a Servlet
Servlet Development Options
Using Tomcat
A Simple Servlet
   Create and Compile the Servlet Source Code
   Start Tomcat
   Start a Web Browser and Request the Servlet
The Servlet API
The javax.servlet Package
   The Servlet Interface
   The ServletConfig Interface
   The ServletContext Interface
   The ServletRequest Interface
   The ServletResponse Interface
   The GenericServlet Class
   The ServletInputStream Class
   The ServletOutputStream Class
   The ServletException Classes
Reading Servlet Parameters
The javax.servlet.http Package
   The HttpServletRequest Interface
   The HttpServletResponse Interface
The HttpSession Interface
The Cookie Class
The HttpServlet Class
Handling HTTP Requests and Responses
  Handling HTTP GET Requests
  Handling HTTP POST Requests
Using Cookies
Session Tracking

Part VI  Appendixes

Appendix A  Using Java’s Documentation Comments

The javadoc Tags
  @author
  {@code}
  @deprecated
  {@docRoot}
  @exception
  @hidden
  {@index}
  {@inheritDoc}
  {@link}
  {@linkplain}
  {@literal}
  @param
  @provides
  @return
  @see
  @serial
  @serialData
  @serialField
  @since
  @throws
  @uses
  {@value}
  @version

The General Form of a Documentation Comment
What javadoc Outputs
Appendix B  An Overview of Java Web Start
What Is Java Web Start?
Four Key Java Web Start Essentials
  Java Web Start Apps Require a JAR File
  Java Web Start Apps Are Signed
  Java Web Start Relies on JNLP
  Linking to the Java Web Start JNLP File
Experimenting with Java Web Start Using the Local File System
  Create a JAR File for ToggleButtonDemo
  Create a Keystore and Sign ToggleButtonDemo.jar
  Create a JNLP File for ToggleButtonDemo
  Create a Short HTML File Called StartTBD.html
  Add ToggleButtonDemo.jnlp to the Exception Site List in the Java
  Control Panel
  Execute ToggleButtonDemo via Your Browser
Running a Java Web Start Application Using javaws
Using Java Web Start with an Applet

Appendix C  Introducing JShell
JShell Basics
  List, Edit, and Rerun Code
  Add a Method
  Create a Class
  Use an Interface
  Evaluate Expressions and Use Built-in Variables
Importing Packages
Exceptions
Some More JShell Commands
Exploring JShell Further

Appendix D  Applet Basics
Two Types of Applets
Applet Basics
The Applet Class
Applet Architecture
An Applet Skeleton
  Applet Initialization and Termination
Java is one of the world’s most important and widely used computer languages. Furthermore, it has held that distinction for many years. Unlike some other computer languages whose influence has waned with the passage of time, Java’s has grown stronger. Java leapt to the forefront of Internet programming with its first release. Each subsequent version has solidified that position. Today, it is still the first and best choice for developing web-based applications. It is also a powerful, general-purpose programming language suitable for a wide variety of purposes. Simply put: much of the modern world runs on Java code. Java really is that important.

A key reason for Java’s success is its agility. Since its original 1.0 release, Java has continually adapted to changes in the programming environment and to changes in the way that programmers program. Most importantly, it has not just followed the trends, it has helped create them. Java’s ability to accommodate the fast rate of change in the computing world is a crucial part of why it has been and continues to be so successful.

Since this book was first published in 1996, it has gone through several editions, each reflecting the ongoing evolution of Java. This is the tenth edition, and it has been updated for Java SE 9 (JDK 9). As a result, this edition of the book contains a substantial amount of new material because Java SE 9 adds several new features to the Java language. The most important is modules, which enable you to specify the relationships and dependencies of the code that comprises an application. They can also affect the accessibility of elements. The addition of modules represents one of the most profound changes made to the Java language, adding both a new syntax element and ten new keywords. Modules also significantly impact the Java API library because its packages are now organized into modules. Furthermore, to support modules, new tools have been added, existing tools have been updated, and a new file format has been defined. Because of their importance, the entirety of Chapter 16 is devoted to modules.

In addition to modules, there are several other new features provided by JDK 9.
One of the most interesting is JShell. JShell is a tool that offers an interactive environment in which it is easy to experiment with code snippets without having to write an entire program. Both beginners and experienced pros will find it quite useful. An introduction to JShell is found in Appendix C. As with previous releases, JDK 9 contains a number of smaller updates and enhancements to both the Java language and its API libraries. Thus, updated material is found throughout this book. One final point: Java SE 9 deprecates applets and the applet API. Thus, they are no longer covered in the main book. However, a brief introduction to applets is provided in Appendix D.

A Book for All Programmers

This book is for all programmers, whether you are a novice or an experienced pro. The beginner will find its carefully paced discussions and many examples especially helpful. Its in-depth coverage of Java’s more advanced features and libraries will appeal to the pro. For both, it offers a lasting resource and handy reference.

What’s Inside

This book is a comprehensive guide to the Java language, describing its syntax, keywords, and fundamental programming principles. Significant portions of the Java API library are also examined. The book is divided into five parts, each focusing on a different aspect of the Java programming environment.

Part I presents an in-depth tutorial of the Java language. It begins with the basics, including such things as data types, operators, control statements, and classes. It then moves on to inheritance, packages, interfaces, exception handling, and multithreading. Next, it describes annotations, enumerations, autoboxing, generics, and lambda expressions. I/O is also introduced. The final chapter in Part I covers modules. As mentioned, modules are the single most important new feature in Java SE 9.

Part II examines key aspects of Java’s standard API library. Topics include strings, I/O, networking, the standard utilities, the Collections Framework, the AWT, event handling, imaging, concurrency (including the Fork/Join Framework), regular expressions, and the stream library.

Part III offers three chapters that introduce Swing.

Part IV presents three chapters that introduce JavaFX.

Part V contains two chapters that show examples of Java in action. The first discusses Java Beans. The second presents an introduction to servlets.
Special Thanks

I want to give special thanks to Patrick Naughton, Joe O’Neil, and Danny Coward.

Patrick Naughton was one of the creators of the Java language. He also helped write the first edition of this book. For example, among many other contributions, much of the material in Chapters 21, 23, and 27 was initially provided by Patrick. His insights, expertise, and energy contributed greatly to the success of that book.

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For Further Study

Java: The Complete Reference is your gateway to the Herb Schildt series of Java programming books. Here are others that you will find of interest:

Herb Schildt’s Java Programming Cookbook
Java: A Beginner’s Guide
Introducing JavaFX 8 Programming
Swing: A Beginner’s Guide
The Art of Java
PART
I  The Java Language

CHAPTER 1  
The History and Evolution of Java

CHAPTER 2  
An Overview of Java

CHAPTER 3  
Data Types, Variables, and Arrays

CHAPTER 4  
Operators

CHAPTER 5  
Control Statements

CHAPTER 6  
Introducing Classes

CHAPTER 7  
A Closer Look at Methods and Classes

CHAPTER 8  
Inheritance

CHAPTER 9  
Packages and Interfaces

CHAPTER 10  
Exception Handling

CHAPTER 11  
Multithreaded Programming

CHAPTER 12  
Enumerations, Autoboxing, and Annotations
<table>
<thead>
<tr>
<th>CHAPTER 13</th>
<th>I/O, Try-with-Resources, and Other Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHAPTER 14</td>
<td>Generics</td>
</tr>
<tr>
<td>CHAPTER 15</td>
<td>Lambda Expressions</td>
</tr>
<tr>
<td>CHAPTER 16</td>
<td>Modules</td>
</tr>
</tbody>
</table>
1 The History and Evolution of Java

To fully understand Java, one must understand the reasons behind its creation, the forces that shaped it, and the legacy that it inherits. Like the successful computer languages that came before, Java is a blend of the best elements of its rich heritage combined with the innovative concepts required by its unique mission. While the remaining chapters of this book describe the practical aspects of Java—including its syntax, key libraries, and applications—this chapter explains how and why Java came about, what makes it so important, and how it has evolved over the years.

Although Java has become inseparably linked with the online environment of the Internet, it is important to remember that Java is first and foremost a programming language. Computer language innovation and development occur for two fundamental reasons:

• To adapt to changing environments and uses
• To implement refinements and improvements in the art of programming

As you will see, the development of Java was driven by both elements in nearly equal measure.

Java’s Lineage

Java is related to C++, which is a direct descendant of C. Much of the character of Java is inherited from these two languages. From C, Java derives its syntax. Many of Java’s object-oriented features were influenced by C++. In fact, several of Java’s defining characteristics come from—or are responses to—its predecessors. Moreover, the creation of Java was deeply rooted in the process of refinement and adaptation that has been occurring in computer programming languages for the past several decades. For these reasons, this section reviews the sequence of events and forces that led to Java. As you will see, each innovation in language design was driven by the need to solve a fundamental problem that the preceding languages could not solve. Java is no exception.

The Birth of Modern Programming: C
The C language shook the computer world. Its impact should not be underestimated, because it fundamentally changed the way programming was approached and thought about. The creation of C was a direct result of the need for a structured, efficient, high-level language that could replace assembly code when creating systems programs. As you may know, when a computer language is designed, trade-offs are often made, such as the following:

- Ease-of-use versus power
- Safety versus efficiency
- Rigidity versus extensibility

Prior to C, programmers usually had to choose between languages that optimized one set of traits or the other. For example, although FORTRAN could be used to write fairly efficient programs for scientific applications, it was not very good for system code. And while BASIC was easy to learn, it wasn’t very powerful, and its lack of structure made its usefulness questionable for large programs. Assembly language can be used to produce highly efficient programs, but it is not easy to learn or use effectively. Further, debugging assembly code can be quite difficult.

Another compounding problem was that early computer languages such as BASIC, COBOL, and FORTRAN were not designed around structured principles. Instead, they relied upon the GOTO as a primary means of program control. As a result, programs written using these languages tended to produce “spaghetti code”—a mass of tangled jumps and conditional branches that make a program virtually impossible to understand. While languages like Pascal are structured, they were not designed for efficiency, and failed to include certain features necessary to make them applicable to a wide range of programs. (Specifically, given the standard dialects of Pascal available at the time, it was not practical to consider using Pascal for systems-level code.)

So, just prior to the invention of C, no one language had reconciled the conflicting attributes that had dogged earlier efforts. Yet the need for such a language was pressing. By the early 1970s, the computer revolution was beginning to take hold, and the demand for software was rapidly outpacing programmers’ ability to produce it. A great deal of effort was being expended in academic circles in an attempt to create a better computer language. But, and perhaps most importantly, a secondary force was beginning to be felt. Computer hardware was finally becoming common enough that a critical mass was being reached. No longer were computers kept behind locked doors. For the first time, programmers were gaining virtually unlimited access to their machines. This allowed the freedom to experiment. It also allowed programmers to begin to create their own tools. On the eve of C’s creation, the stage was set for a quantum leap forward in computer languages.
Invented and first implemented by Dennis Ritchie on a DEC PDP-11 running the UNIX operating system, C was the result of a development process that started with an older language called BCPL, developed by Martin Richards. BCPL influenced a language called B, invented by Ken Thompson, which led to the development of C in the 1970s. For many years, the de facto standard for C was the one supplied with the UNIX operating system and described in *The C Programming Language* by Brian Kernighan and Dennis Ritchie (Prentice-Hall, 1978). C was formally standardized in December 1989, when the American National Standards Institute (ANSI) standard for C was adopted.

The creation of C is considered by many to have marked the beginning of the modern age of computer languages. It successfully synthesized the conflicting attributes that had so troubled earlier languages. The result was a powerful, efficient, structured language that was relatively easy to learn. It also included one other, nearly intangible aspect: it was a *programmer’s* language. Prior to the invention of C, computer languages were generally designed either as academic exercises or by bureaucratic committees. C is different. It was designed, implemented, and developed by real, working programmers, reflecting the way that they approached the job of programming. Its features were honed, tested, thought about, and rethought by the people who actually used the language. The result was a language that programmers liked to use. Indeed, C quickly attracted many followers who had a near-religious zeal for it. As such, it found wide and rapid acceptance in the programmer community. In short, C is a language designed by and for programmers. As you will see, Java inherited this legacy.

**C++: The Next Step**

During the late 1970s and early 1980s, C became the dominant computer programming language, and it is still widely used today. Since C is a successful and useful language, you might ask why a need for something else existed. The answer is *complexity*. Throughout the history of programming, the increasing complexity of programs has driven the need for better ways to manage that complexity. C++ is a response to that need. To better understand why managing program complexity is fundamental to the creation of C++, consider the following.

Approaches to programming have changed dramatically since the invention of the computer. For example, when computers were first invented, programming was done by manually toggling in the binary machine instructions by use of the front panel. As long as programs were just a few hundred instructions long, this approach worked. As programs grew, assembly language was invented so that a programmer could deal with larger, increasingly complex programs by using symbolic representations of the machine instructions. As programs continued to grow, high-level languages were
introduced that gave the programmer more tools with which to handle complexity.

The first widespread language was, of course, FORTRAN. While FORTRAN was an impressive first step, it is hardly a language that encourages clear and easy-to-understand programs. The 1960s gave birth to *structured programming*. This is the method of programming championed by languages such as C. The use of structured languages enabled programmers to write, for the first time, moderately complex programs fairly easily. However, even with structured programming methods, once a project reaches a certain size, its complexity exceeds what a programmer can manage. By the early 1980s, many projects were pushing the structured approach past its limits. To solve this problem, a new way to program was invented, called *object-oriented programming* (OOP). Object-oriented programming is discussed in detail later in this book, but here is a brief definition: OOP is a programming methodology that helps organize complex programs through the use of inheritance, encapsulation, and polymorphism.

In the final analysis, although C is one of the world’s great programming languages, there is a limit to its ability to handle complexity. Once the size of a program exceeds a certain point, it becomes so complex that it is difficult to grasp as a totality. While the precise size at which this occurs differs, depending upon both the nature of the program and the programmer, there is always a threshold at which a program becomes unmanageable. C++ added features that enabled this threshold to be broken, allowing programmers to comprehend and manage larger programs.

C++ was invented by Bjarne Stroustrup in 1979, while he was working at Bell Laboratories in Murray Hill, New Jersey. Stroustrup initially called the new language “C with Classes.” However, in 1983, the name was changed to C++. C++ extends C by adding object-oriented features. Because C++ is built on the foundation of C, it includes all of C’s features, attributes, and benefits. This is a crucial reason for the success of C++ as a language. The invention of C++ was not an attempt to create a completely new programming language. Instead, it was an enhancement to an already highly successful one.

**The Stage Is Set for Java**

By the end of the 1980s and the early 1990s, object-oriented programming using C++ took hold. Indeed, for a brief moment it seemed as if programmers had finally found the perfect language. Because C++ blended the high efficiency and stylistic elements of C with the object-oriented paradigm, it was a language that could be used to create a wide range of programs. However, just as in the past, forces were brewing that would, once again, drive computer language evolution forward. Within a few years, the World Wide Web and the Internet would reach critical mass. This event would precipitate another revolution in programming.
The Creation of Java

Java was conceived by James Gosling, Patrick Naughton, Chris Warth, Ed Frank, and Mike Sheridan at Sun Microsystems, Inc. in 1991. It took 18 months to develop the first working version. This language was initially called “Oak,” but was renamed “Java” in 1995. Between the initial implementation of Oak in the fall of 1992 and the public announcement of Java in the spring of 1995, many more people contributed to the design and evolution of the language. Bill Joy, Arthur van Hoff, Jonathan Payne, Frank Yellin, and Tim Lindholm were key contributors to the maturing of the original prototype.

Somewhat surprisingly, the original impetus for Java was not the Internet! Instead, the primary motivation was the need for a platform-independent (that is, architecture-neutral) language that could be used to create software to be embedded in various consumer electronic devices, such as microwave ovens and remote controls. As you can probably guess, many different types of CPUs are used as controllers. The trouble with C and C++ (and most other languages) is that they are designed to be compiled for a specific target. Although it is possible to compile a C++ program for just about any type of CPU, to do so requires a full C++ compiler targeted for that CPU. The problem is that compilers are expensive and time-consuming to create. An easier—and more cost-efficient—solution was needed. In an attempt to find such a solution, Gosling and others began work on a portable, platform-independent language that could be used to produce code that would run on a variety of CPUs under differing environments. This effort ultimately led to the creation of Java.

About the time that the details of Java were being worked out, a second, and ultimately more important, factor was emerging that would play a crucial role in the future of Java. This second force was, of course, the World Wide Web. Had the Web not taken shape at about the same time that Java was being implemented, Java might have remained a useful but obscure language for programming consumer electronics. However, with the emergence of the World Wide Web, Java was propelled to the forefront of computer language design, because the Web, too, demanded portable programs.

Most programmers learn early in their careers that portable programs are as elusive as they are desirable. While the quest for a way to create efficient, portable (platform-independent) programs is nearly as old as the discipline of programming itself, it had taken a back seat to other, more pressing problems. Further, because (at that time) much of the computer world had divided itself into the three competing camps of Intel, Macintosh, and UNIX, most programmers stayed within their fortified boundaries, and the urgent need for portable code was reduced. However,
with the advent of the Internet and the Web, the old problem of portability returned with a vengeance. After all, the Internet consists of a diverse, distributed universe populated with various types of computers, operating systems, and CPUs. Even though many kinds of platforms are attached to the Internet, users would like them all to be able to run the same program. What was once an irritating but low-priority problem had become a high-profile necessity.

By 1993, it became obvious to members of the Java design team that the problems of portability frequently encountered when creating code for embedded controllers are also found when attempting to create code for the Internet. In fact, the same problem that Java was initially designed to solve on a small scale could also be applied to the Internet on a large scale. This realization caused the focus of Java to switch from consumer electronics to Internet programming. So, while the desire for an architecture-neutral programming language provided the initial spark, the Internet ultimately led to Java’s large-scale success.

As mentioned earlier, Java derives much of its character from C and C++. This is by intent. The Java designers knew that using the familiar syntax of C and echoing the object-oriented features of C++ would make their language appealing to the legions of experienced C/C++ programmers. In addition to the surface similarities, Java shares some of the other attributes that helped make C and C++ successful. First, Java was designed, tested, and refined by real, working programmers. It is a language grounded in the needs and experiences of the people who devised it. Thus, Java is a programmer’s language. Second, Java is cohesive and logically consistent. Third, except for those constraints imposed by the Internet environment, Java gives you, the programmer, full control. If you program well, your programs reflect it. If you program poorly, your programs reflect that, too. Put differently, Java is not a language with training wheels. It is a language for professional programmers.

Because of the similarities between Java and C++, it is tempting to think of Java as simply the “Internet version of C++.” However, to do so would be a large mistake. Java has significant practical and philosophical differences. While it is true that Java was influenced by C++, it is not an enhanced version of C++. For example, Java is neither upwardly nor downwardly compatible with C++. Of course, the similarities with C++ are significant, and if you are a C++ programmer, then you will feel right at home with Java. One other point: Java was not designed to replace C++. Java was designed to solve a certain set of problems. C++ was designed to solve a different set of problems. Both will coexist for many years to come.

As mentioned at the start of this chapter, computer languages evolve for two reasons: to adapt to changes in environment and to implement advances in the art of programming. The environmental change that prompted Java was the need for platform-independent programs destined for distribution on the Internet. However,
Java also embodies changes in the way that people approach the writing of programs. For example, Java enhanced and refined the object-oriented paradigm used by C++, added integrated support for multithreading, and provided a library that simplified Internet access. In the final analysis, though, it was not the individual features of Java that made it so remarkable. Rather, it was the language as a whole. Java was the perfect response to the demands of the then newly emerging, highly distributed computing universe. Java was to Internet programming what C was to system programming: a revolutionary force that changed the world.

**The C# Connection**

The reach and power of Java continues to be felt in the world of computer language development. Many of its innovative features, constructs, and concepts have become part of the baseline for any new language. The success of Java is simply too important to ignore.

Perhaps the most important example of Java’s influence is C#. Created by Microsoft to support the .NET Framework, C# is closely related to Java. For example, both share the same general syntax, support distributed programming, and utilize the same object model. There are, of course, differences between Java and C#, but the overall “look and feel” of these languages is very similar. This “cross-pollination” from Java to C# is the strongest testimonial to date that Java redefined the way we think about and use a computer language.

**How Java Impacted the Internet**

The Internet helped catapult Java to the forefront of programming, and Java, in turn, had a profound effect on the Internet. In addition to simplifying web programming in general, Java innovated a new type of networked program called the applet that changed the way the online world thought about content. Java also addressed some of the thorniest issues associated with the Internet: portability and security. Let’s look more closely at each of these.

**Java Applets**

At the time of Java’s creation, one of its most exciting features was the applet. An applet is a special kind of Java program that is designed to be transmitted over the Internet and automatically executed inside a Java-compatible web browser. If the user clicks a link that contains an applet, the applet will download and run in the browser. Applets were intended to be small programs. They were typically used to display data provided by the server, handle user input, or provide simple functions,
such as a loan calculator, that execute locally, rather than on the server. In essence, the applet allowed some functionality to be moved from the server to the client.

The creation of the applet was important because, at the time, it expanded the universe of objects that can move about freely in cyberspace. In general, there are two very broad categories of objects that are transmitted between the server and the client: passive information and dynamic, active programs. For example, when you read your e-mail, you are viewing passive data. Even when you download a program, the program’s code is still only passive data until you execute it. By contrast, the applet is a dynamic, self-executing program. Such a program is an active agent on the client computer, yet it is initiated by the server.

In the early days of Java, applets were a crucial part of Java programming. They illustrated the power and benefits of Java, added an exciting dimension to web pages, and enabled programmers to explore the full extent of what was possible with Java. Although there are still applets in use today, over time they became less important. As will be explained, beginning with JDK 9, applets are being phased out, with other mechanisms supplying an alternative way of delivering dynamic, active programs via the Web.

Security

As desirable as dynamic, networked programs are, they can also present serious problems in the areas of security and portability. Obviously, a program that downloads and executes automatically on the client computer must be prevented from doing harm. It must also be able to run in a variety of different environments and under different operating systems. As you will see, Java solved these problems in an effective and elegant way. Let’s look a bit more closely at each, beginning with security.

As you are likely aware, every time you download a “normal” program, you are taking a risk, because the code you are downloading might contain a virus, Trojan horse, or other harmful code. At the core of the problem is the fact that malicious code can cause its damage because it has gained unauthorized access to system resources. For example, a virus program might gather private information, such as credit card numbers, bank account balances, and passwords, by searching the contents of your computer’s local file system. In order for Java to enable programs to be safely downloaded and executed on the client computer, it was necessary to prevent them from launching such an attack.

Java achieved this protection by enabling you to confine an application to the Java execution environment and prevent it from accessing other parts of the computer. (You will see how this is accomplished shortly.) The ability to download programs with a degree of confidence that no harm will be done may have been the
single most innovative aspect of Java.

**Portability**

Portability is a major aspect of the Internet because there are many different types of computers and operating systems connected to it. If a Java program were to be run on virtually any computer connected to the Internet, there needed to be some way to enable that program to execute on different systems. In other words, a mechanism that allows the same application to be downloaded and executed by a wide variety of CPUs, operating systems, and browsers is required. It is not practical to have different versions of the application for different computers. The same code must work on all computers. Therefore, some means of generating portable executable code was needed. As you will soon see, the same mechanism that helps ensure security also helps create portability.

**Java’s Magic: The Bytecode**

The key that allows Java to solve both the security and the portability problems just described is that the output of a Java compiler is not executable code. Rather, it is bytecode. **Bytecode** is a highly optimized set of instructions designed to be executed by the Java run-time system, which is called the **Java Virtual Machine (JVM)**. In essence, the original JVM was designed as an interpreter for bytecode. This may come as a bit of a surprise since many modern languages are designed to be compiled into executable code because of performance concerns. However, the fact that a Java program is executed by the JVM helps solve the major problems associated with web-based programs. Here is why.

Translating a Java program into bytecode makes it much easier to run a program in a wide variety of environments because only the JVM needs to be implemented for each platform. Once the run-time package exists for a given system, any Java program can run on it. Remember, although the details of the JVM will differ from platform to platform, all understand the same Java bytecode. If a Java program were compiled to native code, then different versions of the same program would have to exist for each type of CPU connected to the Internet. This is, of course, not a feasible solution. Thus, the execution of bytecode by the JVM is the easiest way to create truly portable programs.

The fact that a Java program is executed by the JVM also helps to make it secure. Because the JVM is in control, it manages program execution. Thus, it is possible for the JVM to create a restricted execution environment, called the **sandbox**, that contains the program, preventing unrestricted access to the machine. Safety is also enhanced by certain restrictions that exist in the Java language.
In general, when a program is compiled to an intermediate form and then interpreted by a virtual machine, it runs slower than it would run if compiled to executable code. However, with Java, the differential between the two is not so great. Because bytecode has been highly optimized, the use of bytecode enables the JVM to execute programs much faster than you might expect.

Although Java was designed as an interpreted language, there is nothing about Java that prevents on-the-fly compilation of bytecode into native code in order to boost performance. For this reason, the HotSpot technology was introduced not long after Java’s initial release. HotSpot provides a Just-In-Time (JIT) compiler for bytecode. When a JIT compiler is part of the JVM, selected portions of bytecode are compiled into executable code in real time, on a piece-by-piece, demand basis. It is important to understand that an entire Java program is not compiled into executable code all at once. Instead, a JIT compiler compiles code as it is needed, during execution. Furthermore, not all sequences of bytecode are compiled—only those that will benefit from compilation. The remaining code is simply interpreted. However, the just-in-time approach still yields a significant performance boost. Even when dynamic compilation is applied to bytecode, the portability and safety features still apply, because the JVM is still in charge of the execution environment.

One other point: Beginning with JDK 9, selected Java environments will also include an ahead-of-time compiler that can be used to compile bytecode into native code prior to execution by the JVM, rather than on-the-fly. Ahead-of-time compilation is a specialized feature, and it does not replace Java’s traditional approach just described. Furthermore, ahead-of-time compilation has several restrictions. Here are three examples: at the time of this writing, ahead-of-time compilation is for experimental purposes only, is available only on 64-bit Linux versions of Java, and precompiled code must be executed on the same (or similarly configured) system that compiled the code. Thus, ahead-of-time compilation reduces portability. Because of the highly specialized nature of ahead-of-time compilation, it is not discussed further in this book.

Moving Beyond Applets

As explained previously, in the early years of Java, applets were a crucial part of Java programming. They not only added excitement to a web page, they were a highly visible part of Java, which added to its charisma. However, applets rely on a Java browser plug-in. Thus, for an applet to work, the browser must support it. Recently, support for the Java browser plug-in has been waning. Simply put, without browser support, applets are not viable. Because of this, beginning with JDK 9, Java’s support for applets has been deprecated. In the language of Java, deprecated
means that a feature is still available but flagged as obsolete. A deprecated feature is subject to removal in a future release. Thus, deprecated features should not be used for new code.

Various alternatives to applets are in place, with arguably the most important being Java Web Start. Java Web Start enables an application to be dynamically downloaded from a web page. The difference is that the application runs on its own, not inside the browser. Thus, it does not rely on the Java plug-in. Java Web Start is a deployment mechanism that works with many types of Java programs. Although a detailed discussion of deployment strategies is beyond the scope of this book, because of its importance, a brief introduction to Java Web Start is presented in Appendix B.

Servlets: Java on the Server Side

Client side code is just one half of the client/server equation. Not long after the initial release of Java, it became obvious that Java would also be useful on the server side. The result was the servlet. A servlet is a small program that executes on the server.

Servlets are used to create dynamically generated content that is then served to the client. For example, an online store might use a servlet to look up the price for an item in a database. The price information is then used to dynamically generate a web page that is sent to the browser. Although dynamically generated content is available through mechanisms such as CGI (Common Gateway Interface), the servlet offers several advantages, including increased performance.

Because servlets (like all Java programs) are compiled into bytecode and executed by the JVM, they are highly portable. Thus, the same servlet can be used in a variety of different server environments. The only requirements are that the server support the JVM and a servlet container.

The Java Buzzwords

No discussion of Java’s history is complete without a look at the Java buzzwords. Although the fundamental forces that necessitated the invention of Java are portability and security, other factors also played an important role in molding the final form of the language. The key considerations were summed up by the Java team in the following list of buzzwords:

- Simple
- Secure
Portable
Object-oriented
Robust
Multithreaded
Architecture-neutral
Interpreted
High performance
Distributed
Dynamic

Two of these buzzwords have already been discussed: secure and portable. Let’s examine what each of the others implies.

Simple
Java was designed to be easy for the professional programmer to learn and use effectively. Assuming that you have some programming experience, you will not find Java hard to master. If you already understand the basic concepts of object-oriented programming, learning Java will be even easier. Best of all, if you are an experienced C++ programmer, moving to Java will require very little effort. Because Java inherits the C/C++ syntax and many of the object-oriented features of C++, most programmers have little trouble learning Java.

Object-Oriented
Although influenced by its predecessors, Java was not designed to be source-code compatible with any other language. This allowed the Java team the freedom to design with a blank slate. One outcome of this was a clean, usable, pragmatic approach to objects. Borrowing liberally from many seminal object-software environments of the last few decades, Java manages to strike a balance between the purist’s “everything is an object” paradigm and the pragmatist’s “stay out of my way” model. The object model in Java is simple and easy to extend, while primitive types, such as integers, are kept as high-performance nonobjects.

Robust
The multiplatformed environment of the Web places extraordinary demands on a program, because the program must execute reliably in a variety of systems. Thus, the ability to create robust programs was given a high priority in the design of Java. To gain reliability, Java restricts you in a few key areas to force you to find your
mistakes early in program development. At the same time, Java frees you from having to worry about many of the most common causes of programming errors. Because Java is a strictly typed language, it checks your code at compile time. However, it also checks your code at run time. Many hard-to-track-down bugs that often turn up in hard-to-reproduce run-time situations are simply impossible to create in Java. Knowing that what you have written will behave in a predictable way under diverse conditions is a key feature of Java.

To better understand how Java is robust, consider two of the main reasons for program failure: memory management mistakes and mishandled exceptional conditions (that is, run-time errors). Memory management can be a difficult, tedious task in traditional programming environments. For example, in C/C++, the programmer will often manually allocate and free dynamic memory. This sometimes leads to problems, because programmers will either forget to free memory that has been previously allocated or, worse, try to free some memory that another part of their code is still using. Java virtually eliminates these problems by managing memory allocation and deallocation for you. (In fact, deallocation is completely automatic, because Java provides garbage collection for unused objects.) Exceptional conditions in traditional environments often arise in situations such as division by zero or “file not found,” and they must be managed with clumsy and hard-to-read constructs. Java helps in this area by providing object-oriented exception handling. In a well-written Java program, all run-time errors can—and should—be managed by your program.

**Multithreaded**

Java was designed to meet the real-world requirement of creating interactive, networked programs. To accomplish this, Java supports multithreaded programming, which allows you to write programs that do many things simultaneously. The Java run-time system comes with an elegant yet sophisticated solution for multiprocess synchronization that enables you to construct smoothly running interactive systems. Java’s easy-to-use approach to multithreading allows you to think about the specific behavior of your program, not the multitasking subsystem.

**Architecture-Neutral**

A central issue for the Java designers was that of code longevity and portability. At the time of Java’s creation, one of the main problems facing programmers was that no guarantee existed that if you wrote a program today, it would run tomorrow—even on the same machine. Operating system upgrades, processor upgrades, and changes in core system resources can all combine to make a program malfunction.
The Java designers made several hard decisions in the Java language and the Java Virtual Machine in an attempt to alter this situation. Their goal was “write once; run anywhere, any time, forever.” To a great extent, this goal was accomplished.

**Interpreted and High Performance**

As described earlier, Java enables the creation of cross-platform programs by compiling into an intermediate representation called Java bytecode. This code can be executed on any system that implements the Java Virtual Machine. Most previous attempts at cross-platform solutions have done so at the expense of performance. As explained earlier, the Java bytecode was carefully designed so that it would be easy to translate directly into native machine code for very high performance by using a just-in-time compiler. Java run-time systems that provide this feature lose none of the benefits of the platform-independent code.

**Distributed**

Java is designed for the distributed environment of the Internet because it handles TCP/IP protocols. In fact, accessing a resource using a URL is not much different from accessing a file. Java also supports Remote Method Invocation (RMI). This feature enables a program to invoke methods across a network.

**Dynamic**

Java programs carry with them substantial amounts of run-time type information that is used to verify and resolve accesses to objects at run time. This makes it possible to dynamically link code in a safe and expedient manner. This is crucial to the robustness of the Java environment, in which small fragments of bytecode may be dynamically updated on a running system.

**The Evolution of Java**

The initial release of Java was nothing short of revolutionary, but it did not mark the end of Java’s era of rapid innovation. Unlike most other software systems that usually settle into a pattern of small, incremental improvements, Java continued to evolve at an explosive pace. Soon after the release of Java 1.0, the designers of Java had already created Java 1.1. The features added by Java 1.1 were more significant and substantial than the increase in the minor revision number would have you think. Java 1.1 added many new library elements, redefined the way events are handled, and reconfigured many features of the 1.0 library. It also deprecated (rendered
obsolete) several features originally defined by Java 1.0. Thus, Java 1.1 both added to and subtracted from attributes of its original specification.

The next major release of Java was Java 2, where the “2” indicates “second generation.” The creation of Java 2 was a watershed event, marking the beginning of Java’s “modern age.” The first release of Java 2 carried the version number 1.2. It may seem odd that the first release of Java 2 used the 1.2 version number. The reason is that it originally referred to the internal version number of the Java libraries, but then was generalized to refer to the entire release. With Java 2, Sun repackaged the Java product as J2SE (Java 2 Platform Standard Edition), and the version numbers began to be applied to that product.

Java 2 added support for a number of new features, such as Swing and the Collections Framework, and it enhanced the Java Virtual Machine and various programming tools. Java 2 also contained a few deprecations. The most important affected the **Thread** class in which the methods `suspend()`, `resume()`, and `stop()` were deprecated.

J2SE 1.3 was the first major upgrade to the original Java 2 release. For the most part, it added to existing functionality and “tightened up” the development environment. In general, programs written for version 1.2 and those written for version 1.3 are source-code compatible. Although version 1.3 contained a smaller set of changes than the preceding three major releases, it was nevertheless important.

The release of J2SE 1.4 further enhanced Java. This release contained several important upgrades, enhancements, and additions. For example, it added the new keyword `assert`, chained exceptions, and a channel-based I/O subsystem. It also made changes to the Collections Framework and the networking classes. In addition, numerous small changes were made throughout. Despite the significant number of new features, version 1.4 maintained nearly 100 percent source-code compatibility with prior versions.

The next release of Java was J2SE 5, and it was revolutionary. Unlike most of the previous Java upgrades, which offered important, but measured improvements, J2SE 5 fundamentally expanded the scope, power, and range of the language. To grasp the magnitude of the changes that J2SE 5 made to Java, consider the following list of its major new features:

- Generics
- Annotations
- Autoboxing and auto-unboxing
- Enumerations
- Enhanced, for-each style `for` loop
- Variable-length arguments (varargs)
This is not a list of minor tweaks or incremental upgrades. Each item in the list represented a significant addition to the Java language. Some, such as generics, the enhanced for, and varargs, introduced new syntax elements. Others, such as autoboxing and auto-unboxing, altered the semantics of the language. Annotations added an entirely new dimension to programming. In all cases, the impact of these additions went beyond their direct effects. They changed the very character of Java itself.

The importance of these new features is reflected in the use of the version number “5.” The next version number for Java would normally have been 1.5. However, the new features were so significant that a shift from 1.4 to 1.5 just didn’t seem to express the magnitude of the change. Instead, Sun elected to increase the version number to 5 as a way of emphasizing that a major event was taking place. Thus, it was named J2SE 5, and the developer’s kit was called JDK 5. However, in order to maintain consistency, Sun decided to use 1.5 as its internal version number, which is also referred to as the developer version number. The “5” in J2SE 5 is called the product version number.

The next release of Java was called Java SE 6. Sun once again decided to change the name of the Java platform. First, notice that the “2” was dropped. Thus, the platform was now named Java SE, and the official product name was Java Platform, Standard Edition 6. The Java Development Kit was called JDK 6. As with J2SE 5, the 6 in Java SE 6 is the product version number. The internal, developer version number is 1.6.

Java SE 6 built on the base of J2SE 5, adding incremental improvements. Java SE 6 added no major features to the Java language proper, but it did enhance the API libraries, added several new packages, and offered improvements to the runtime. It also went through several updates during its (in Java terms) long life cycle, with several upgrades added along the way. In general, Java SE 6 served to further solidify the advances made by J2SE 5.

Java SE 7 was the next release of Java, with the Java Development Kit being called JDK 7, and an internal version number of 1.7. Java SE 7 was the first major release of Java since Sun Microsystems was acquired by Oracle. Java SE 7 contained many new features, including significant additions to the language and the API libraries. Upgrades to the Java run-time system that support non-Java languages were also included, but it is the language and library additions that were of most interest to Java programmers.
The new language features were developed as part of Project Coin. The purpose of Project Coin was to identify a number of small changes to the Java language that would be incorporated into JDK 7. Although these features were collectively referred to as “small,” the effects of these changes have been quite large in terms of the code they impact. In fact, for many programmers, these changes may well have been the most important new features in Java SE 7. Here is a list of the language features added by JDK 7:

- A `String` can now control a `switch` statement.
- Binary integer literals.
- Underscores in numeric literals.
- An expanded `try` statement, called `try-with-resources`, that supports automatic resource management. (For example, streams can be closed automatically when they are no longer needed.)
- Type inference (via the `diamond` operator) when constructing a generic instance.
- Enhanced exception handling in which two or more exceptions can be caught by a single `catch` (multi-catch) and better type checking for exceptions that are rethrown.
- Although not a syntax change, the compiler warnings associated with some types of varargs methods were improved, and you have more control over the warnings.

As you can see, even though the Project Coin features were considered small changes to the language, their benefits were much larger than the qualifier “small” would suggest. In particular, the `try-with-resources` statement has profoundly affected the way that stream-based code is written. Also, the ability to use a `String` to control a `switch` statement was a long-desired improvement that simplified coding in many situations.

Java SE 7 made several additions to the Java API library. Two of the most important were the enhancements to the NIO Framework and the addition of the Fork/Join Framework. NIO (which originally stood for `New I/O`) was added to Java in version 1.4. However, the changes added by Java SE 7 fundamentally expanded its capabilities. So significant were the changes, that the term `NIO.2` is often used.

The Fork/Join Framework provides important support for parallel programming. Parallel programming is the name commonly given to the techniques that make effective use of computers that contain more than one processor, including multicore systems. The advantage that multicore environments offer is the prospect of significantly increased program performance. The Fork/Join Framework addressed
parallel programming by:

- Simplifying the creation and use of tasks that can execute concurrently
- Automatically making use of multiple processors

Therefore, by using the Fork/Join Framework, you can easily create scaleable applications that automatically take advantage of the processors available in the execution environment. Of course, not all algorithms lend themselves to parallelization, but for those that do, a significant improvement in execution speed can be obtained.

The next release of Java was Java SE 8, with the developer’s kit being called JDK 8. It has an internal version number of 1.8. JDK 8 was a significant upgrade to the Java language because of the inclusion of a far-reaching new language feature: the **lambda expression**. The impact of lambda expressions was, and will continue to be, profound, changing both the way that programming solutions are conceptualized and how Java code is written. As explained in detail in Chapter 15, lambda expressions add functional programming features to Java. In the process, lambda expressions can simplify and reduce the amount of source code needed to create certain constructs, such as some types of anonymous classes. The addition of lambda expressions also caused a new operator (the \(-\rightarrow\)) and a new syntax element to be added to the language.

The inclusion of lambda expressions has also had a wide-ranging effect on the Java libraries, with new features being added to take advantage of them. One of the most important was the new stream API, which is packaged in `java.util.stream`. The stream API supports pipeline operations on data and is optimized for lambda expressions. Another new package was `java.util.function`. It defines a number of **functional interfaces**, which provide additional support for lambda expressions. Other new lambda-related features are found throughout the API library.

Another lambda-inspired feature affects **interface**. Beginning with JDK 8, it is now possible to define a default implementation for a method specified by an interface. If no implementation for a default method is created, then the default defined by the interface is used. This feature enables interfaces to be gracefully evolved over time because a new method can be added to an interface without breaking existing code. It can also streamline the implementation of an interface when the defaults are appropriate. Other new features in JDK 8 include a new time and date API, type annotations, and the ability to use parallel processing when sorting an array, among others. JDK 8 also bundled support for JavaFX, Java’s latest GUI application framework. JavaFX is expected to ultimately replace Swing for most GUI-based projects. Part IV of this book provides an introduction to it.
The newest release of Java is Java SE 9. The developer’s kit is called JDK 9. With the release of JDK 9, the internal version number is also 9. JDK 9 represents a major Java release, incorporating significant enhancements to both the Java language and its libraries. Like the JDK 5 and JDK 8 releases, JDK 9 affects the Java language and its API libraries in fundamental ways.

The primary new feature is modules, which enable you to specify the relationship and dependencies of the code that comprises an application. Modules also add another dimension to Java’s access control features. The inclusion of modules caused a new syntax element and several keywords to be added to Java. Furthermore, a tool called jlink was added to the JDK, which enables a programmer to create a run-time image of an application that contains only the necessary modules. A new file type, called JMOD, was created. Modules also have a profound affect on the API library because, beginning with JDK 9, the library packages are now organized into modules.

Although modules constitute a major Java enhancement, they are conceptually simple and straightforward. Furthermore, because pre-module legacy code is fully supported, modules can be integrated into the development process on your timeline. There is no need to immediately change any preexisting code to handle modules. In short, modules add substantial functionality without altering the essence of Java.

In addition to modules, JDK 9 includes many other new features. One of particular interest is JShell, which is a tool that supports interactive program experimentation and learning. (An introduction to JShell is found in Appendix C.) Another interesting upgrade is support for private interface methods. Their inclusion further enhances JDK 8’s support for default methods in interfaces. JDK 9 adds a search feature to the javadoc tool and a new tag called @index to support it. As with previous releases, JDK 9 contains a number of enhancements to Java’s API libraries.

As a general rule, in any Java release, it is the new features that receive the most attention. However, there is one high-profile aspect of Java that is deprecated by JDK 9: applets. Beginning with JDK 9, applets are no longer recommended for new projects. As explained earlier in this chapter, because of waning browser support for applets (and other factors), JDK 9 deprecates the entire applet API. At this time, the use of Java Web Start is recommended for deployment over the Internet. Because applets are being phased out and not recommended for new code, they are no longer discussed in detail in this book. However, a brief introduction to applets is provided in Appendix D.

In the final analysis, JDK 9 continues Java’s legacy of innovation, ensuring that Java remains the vibrant, nimble language that the programming world has come to
expect. The material in this book has been updated to reflect Java SE 9 (JDK 9), with many new features, updates, and additions indicated throughout.

**A Culture of Innovation**

Since the beginning, Java has been at the center of a culture of innovation. Its original release redefined programming for the Internet. The Java Virtual Machine (JVM) and bytecode changed the way we think about security and portability. Portable code made the Web come alive. The Java Community Process (JCP) redefined the way that new ideas are assimilated into the language. The world of Java has never stood still for very long. Java SE 9 is the latest release in Java’s ongoing, dynamic history.
CHAPTER
2 An Overview of Java

As in all other computer languages, the elements of Java do not exist in isolation. Rather, they work together to form the language as a whole. However, this interrelatedness can make it difficult to describe one aspect of Java without involving several others. Often a discussion of one feature implies prior knowledge of another. For this reason, this chapter presents a quick overview of several key features of Java. The material described here will give you a foothold that will allow you to write and understand simple programs. Most of the topics discussed will be examined in greater detail in the remaining chapters of Part I.

Object-Oriented Programming

Object-oriented programming (OOP) is at the core of Java. In fact, all Java programs are to at least some extent object-oriented. OOP is so integral to Java that it is best to understand its basic principles before you begin writing even simple Java programs. Therefore, this chapter begins with a discussion of the theoretical aspects of OOP.

Two Paradigms

All computer programs consist of two elements: code and data. Furthermore, a program can be conceptually organized around its code or around its data. That is, some programs are written around “what is happening” and others are written around “who is being affected.” These are the two paradigms that govern how a program is constructed. The first way is called the process-oriented model. This approach characterizes a program as a series of linear steps (that is, code). The process-oriented model can be thought of as code acting on data. Procedural languages such as C employ this model to considerable success. However, as mentioned in Chapter 1, problems with this approach appear as programs grow larger and more complex.

To manage increasing complexity, the second approach, called object-oriented programming, was conceived. Object-oriented programming organizes a program around its data (that is, objects) and a set of well-defined interfaces to that data. An object-oriented program can be characterized as data controlling access to code. As you will see, by switching the controlling entity to data, you can achieve several organizational benefits.
Abstraction

An essential element of object-oriented programming is *abstraction*. Humans manage complexity through abstraction. For example, people do not think of a car as a set of tens of thousands of individual parts. They think of it as a well-defined object with its own unique behavior. This abstraction allows people to use a car to drive to the grocery store without being overwhelmed by the complexity of the individual parts. They can ignore the details of how the engine, transmission, and braking systems work. Instead, they are free to utilize the object as a whole.

A powerful way to manage abstraction is through the use of hierarchical classifications. This allows you to layer the semantics of complex systems, breaking them into more manageable pieces. From the outside, the car is a single object. Once inside, you see that the car consists of several subsystems: steering, brakes, sound system, seat belts, heating, cellular phone, and so on. In turn, each of these subsystems is made up of more specialized units. For instance, the sound system might consist of a radio, a CD player, and/or MP3 player. The point is that you manage the complexity of the car (or any other complex system) through the use of hierarchical abstractions.

Hierarchical abstractions of complex systems can also be applied to computer programs. The data from a traditional process-oriented program can be transformed by abstraction into its component objects. A sequence of process steps can become a collection of messages between these objects. Thus, each of these objects describes its own unique behavior. You can treat these objects as concrete entities that respond to messages telling them to *do something*. This is the essence of object-oriented programming.

Object-oriented concepts form the heart of Java just as they form the basis for human understanding. It is important that you understand how these concepts translate into programs. As you will see, object-oriented programming is a powerful and natural paradigm for creating programs that survive the inevitable changes accompanying the life cycle of any major software project, including conception, growth, and aging. For example, once you have well-defined objects and clean, reliable interfaces to those objects, you can gracefully decommission or replace parts of an older system without fear.

The Three OOP Principles

All object-oriented programming languages provide mechanisms that help you implement the object-oriented model. They are encapsulation, inheritance, and polymorphism. Let’s take a look at these concepts now.
Encapsulation

*Encapsulation* is the mechanism that binds together code and the data it manipulates, and keeps both safe from outside interference and misuse. One way to think about encapsulation is as a protective wrapper that prevents the code and data from being arbitrarily accessed by other code defined outside the wrapper. Access to the code and data inside the wrapper is tightly controlled through a well-defined interface. To relate this to the real world, consider the automatic transmission on an automobile. It encapsulates hundreds of bits of information about your engine, such as how much you are accelerating, the pitch of the surface you are on, and the position of the shift lever. You, as the user, have only one method of affecting this complex encapsulation: by moving the gear-shift lever. You can’t affect the transmission by using the turn signal or windscreen wipers, for example. Thus, the gear-shift lever is a well-defined (indeed, unique) interface to the transmission. Further, what occurs inside the transmission does not affect objects outside the transmission. For example, shifting gears does not turn on the headlights! Because an automatic transmission is encapsulated, dozens of car manufacturers can implement one in any way they please. However, from the driver’s point of view, they all work the same. This same idea can be applied to programming. The power of encapsulated code is that everyone knows how to access it and thus can use it regardless of the implementation details—and without fear of unexpected side effects.

In Java, the basis of encapsulation is the class. Although the class will be examined in great detail later in this book, the following brief discussion will be helpful now. A *class* defines the structure and behavior (data and code) that will be shared by a set of objects. Each object of a given class contains the structure and behavior defined by the class, as if it were stamped out by a mold in the shape of the class. For this reason, objects are sometimes referred to as *instances of a class*. Thus, a class is a logical construct; an object has physical reality.

When you create a class, you will specify the code and data that constitute that class. Collectively, these elements are called *members* of the class. Specifically, the data defined by the class are referred to as *member variables* or *instance variables*. The code that operates on that data is referred to as *member methods* or just *methods*. (If you are familiar with C/C++, it may help to know that what a Java programmer calls a *method*, a C/C++ programmer calls a *function.*) In properly written Java programs, the methods define how the member variables can be used. This means that the behavior and interface of a class are defined by the methods that operate on its instance data.

Since the purpose of a class is to encapsulate complexity, there are mechanisms for hiding the complexity of the implementation inside the class. Each method or variable in a class may be marked private or public. The *public* interface of a class
represents everything that external users of the class need to know, or may know. The private methods and data can only be accessed by code that is a member of the class. Therefore, any other code that is not a member of the class cannot access a private method or variable. Since the private members of a class may only be accessed by other parts of your program through the class’ public methods, you can ensure that no improper actions take place. Of course, this means that the public interface should be carefully designed not to expose too much of the inner workings of a class (see Figure 2-1).

![Figure 2-1](image)

**Figure 2-1**  Encapsulation: public methods can be used to protect private data.

**Inheritance**

*Inheritance* is the process by which one object acquires the properties of another object. This is important because it supports the concept of hierarchical classification. As mentioned earlier, most knowledge is made manageable by hierarchical (that is, top-down) classifications. For example, a Golden Retriever is part of the classification *dog*, which in turn is part of the *mammal* class, which is under the larger class *animal*. Without the use of hierarchies, each object would need to define all of its characteristics explicitly. However, by use of inheritance, an object need only define those qualities that make it unique within its class. It can inherit its general attributes from its parent. Thus, it is the inheritance mechanism
that makes it possible for one object to be a specific instance of a more general case. Let’s take a closer look at this process.

Most people naturally view the world as made up of objects that are related to each other in a hierarchical way, such as animals, mammals, and dogs. If you wanted to describe animals in an abstract way, you would say they have some attributes, such as size, intelligence, and type of skeletal system. Animals also have certain behavioral aspects; they eat, breathe, and sleep. This description of attributes and behavior is the class definition for animals.

If you wanted to describe a more specific class of animals, such as mammals, they would have more specific attributes, such as type of teeth and mammary glands. This is known as a subclass of animals, where animals are referred to as mammals’ superclass.

Since mammals are simply more precisely specified animals, they inherit all of the attributes from animals. A deeply inherited subclass inherits all of the attributes from each of its ancestors in the class hierarchy.

Inheritance interacts with encapsulation as well. If a given class encapsulates some attributes, then any subclass will have the same attributes plus any that it adds as part of its specialization (see Figure 2-2). This is a key concept that lets object-oriented programs grow in complexity linearly rather than geometrically. A new subclass inherits all of the attributes of all of its ancestors. It does not have unpredictable interactions with the majority of the rest of the code in the system.
Figure 2-2  Labrador inherits the encapsulation of all its superclasses.
Polymorphism

Polymorphism (from Greek, meaning "many forms") is a feature that allows one interface to be used for a general class of actions. The specific action is determined by the exact nature of the situation. Consider a stack (which is a last-in, first-out list). You might have a program that requires three types of stacks. One stack is used for integer values, one for floating-point values, and one for characters. The algorithm that implements each stack is the same, even though the data being stored differs. In a non–object-oriented language, you would be required to create three different sets of stack routines, with each set using different names. However, because of polymorphism, in Java you can specify a general set of stack routines that all share the same names.

More generally, the concept of polymorphism is often expressed by the phrase “one interface, multiple methods.” This means that it is possible to design a generic interface to a group of related activities. This helps reduce complexity by allowing the same interface to be used to specify a general class of action. It is the compiler’s job to select the specific action (that is, method) as it applies to each situation. You, the programmer, do not need to make this selection manually. You need only remember and utilize the general interface.

Extending the dog analogy, a dog’s sense of smell is polymorphic. If the dog smells a cat, it will bark and run after it. If the dog smells its food, it will salivate and run to its bowl. The same sense of smell is at work in both situations. The difference is what is being smelled, that is, the type of data being operated upon by the dog’s nose! This same general concept can be implemented in Java as it applies to methods.
within a Java program.

**Polymorphism, Encapsulation, and Inheritance Work Together**

When properly applied, polymorphism, encapsulation, and inheritance combine to produce a programming environment that supports the development of far more robust and scaleable programs than does the process-oriented model. A well-designed hierarchy of classes is the basis for reusing the code in which you have invested time and effort developing and testing. Encapsulation allows you to migrate your implementations over time without breaking the code that depends on the public interface of your classes. Polymorphism allows you to create clean, sensible, readable, and resilient code.

Of the two real-world examples, the automobile more completely illustrates the power of object-oriented design. Dogs are fun to think about from an inheritance standpoint, but cars are more like programs. All drivers rely on inheritance to drive different types (subclasses) of vehicles. Whether the vehicle is a school bus, a Mercedes sedan, a Porsche, or the family minivan, drivers can all more or less find and operate the steering wheel, the brakes, and the accelerator. After a bit of gear grinding, most people can even manage the difference between a stick shift and an automatic, because they fundamentally understand their common superclass, the transmission.

People interface with encapsulated features on cars all the time. The brake and gas pedals hide an incredible array of complexity with an interface so simple you can operate them with your feet! The implementation of the engine, the style of brakes, and the size of the tires have no effect on how you interface with the class definition of the pedals.

The final attribute, polymorphism, is clearly reflected in the ability of car manufacturers to offer a wide array of options on basically the same vehicle. For example, you can get an antilock braking system or traditional brakes, power or rack-and-pinion steering, and 4-, 6-, or 8-cylinder engines. Either way, you will still press the brake pedal to stop, turn the steering wheel to change direction, and press the accelerator when you want to move. The same interface can be used to control a number of different implementations.

As you can see, it is through the application of encapsulation, inheritance, and polymorphism that the individual parts are transformed into the object known as a car. The same is also true of computer programs. By the application of object-oriented principles, the various parts of a complex program can be brought together to form a cohesive, robust, maintainable whole.
As mentioned at the start of this section, every Java program is object-oriented. Or, put more precisely, every Java program involves encapsulation, inheritance, and polymorphism. Although the short example programs shown in the rest of this chapter and in the next few chapters may not seem to exhibit all of these features, they are nevertheless present. As you will see, many of the features supplied by Java are part of its built-in class libraries, which do make extensive use of encapsulation, inheritance, and polymorphism.

A First Simple Program

Now that the basic object-oriented underpinning of Java has been discussed, let’s look at some actual Java programs. Let’s start by compiling and running the short sample program shown here. As you will see, this involves a little more work than you might imagine.

```java
/*
   This is a simple Java program.
   Call this file "Example.java".
*/
class Example {
   // Your program begins with a call to main().
   public static void main(String args[]) {
      System.out.println("This is a simple Java program.");
   }
}
```

NOTE The descriptions that follow use the standard Java SE 9 Development Kit (JDK 9), which is available from Oracle. If you are using an integrated development environment (IDE), then you will need to follow a different procedure for compiling and executing Java programs. In this case, consult your IDE’s documentation for details.

Entering the Program

For most computer languages, the name of the file that holds the source code to a program is immaterial. However, this is not the case with Java. The first thing that you must learn about Java is that the name you give to a source file is very important. For this example, the name of the source file should be Example.java. Let’s see why.

In Java, a source file is officially called a compilation unit. It is a text file that contains (among other things) one or more class definitions. (For now, we will be
using source files that contain only one class.) The Java compiler requires that a source file use the .java filename extension.

As you can see by looking at the program, the name of the class defined by the program is also Example. This is not a coincidence. In Java, all code must reside inside a class. By convention, the name of the main class should match the name of the file that holds the program. You should also make sure that the capitalization of the filename matches the class name. The reason for this is that Java is case-sensitive. At this point, the convention that filenames correspond to class names may seem arbitrary. However, this convention makes it easier to maintain and organize your programs.

Compiling the Program

To compile the Example program, execute the compiler, javac, specifying the name of the source file on the command line, as shown here:

C:\>javac Example.java

The javac compiler creates a file called Example.class that contains the bytecode version of the program. As discussed earlier, the Java bytecode is the intermediate representation of your program that contains instructions the Java Virtual Machine will execute. Thus, the output of javac is not code that can be directly executed.

To actually run the program, you must use the Java application launcher called java. To do so, pass the class name Example as a command-line argument, as shown here:

C:\>java Example

When the program is run, the following output is displayed:

This is a simple Java program.

When Java source code is compiled, each individual class is put into its own output file named after the class and using the .class extension. This is why it is a good idea to give your Java source files the same name as the class they contain—the name of the source file will match the name of the .class file. When you execute java as just shown, you are actually specifying the name of the class that you want to execute. It will automatically search for a file by that name that has the .class extension. If it finds the file, it will execute the code contained in the specified class.

A Closer Look at the First Sample Program
Although Example.java is quite short, it includes several key features that are common to all Java programs. Let’s closely examine each part of the program.

The program begins with the following lines:

```java
/*
   This is a simple Java program.
   Call this file "Example.java".
*/
```

This is a comment. Like most other programming languages, Java lets you enter a remark into a program’s source file. The contents of a comment are ignored by the compiler. Instead, a comment describes or explains the operation of the program to anyone who is reading its source code. In this case, the comment describes the program and reminds you that the source file should be called Example.java. Of course, in real applications, comments generally explain how some part of the program works or what a specific feature does.

Java supports three styles of comments. The one shown at the top of the program is called a multiline comment. This type of comment must begin with /* and end with */. Anything between these two comment symbols is ignored by the compiler. As the name suggests, a multiline comment may be several lines long.

The next line of code in the program is shown here:

```java
class Example {
```

This line uses the keyword class to declare that a new class is being defined. Example is an identifier that is the name of the class. The entire class definition, including all of its members, will be between the opening curly brace ({) and the closing curly brace (}). For the moment, don’t worry too much about the details of a class except to note that in Java, all program activity occurs within one. This is one reason why all Java programs are (at least a little bit) object-oriented.

The next line in the program is the single-line comment, shown here:

```java
// Your program begins with a call to main().
```

This is the second type of comment supported by Java. A single-line comment begins with // and ends at the end of the line. As a general rule, programmers use multiline comments for longer remarks and single-line comments for brief, line-by-line descriptions. The third type of comment, a documentation comment, will be discussed in the “Comments” section later in this chapter.

The next line of code is shown here:

```java
public static void main(String args[]) {
```
This line begins the `main()` method. As the comment preceding it suggests, this is the line at which the program will begin executing. As a general rule, a Java program begins execution by calling `main()`. The full meaning of each part of this line cannot be given now, since it involves a detailed understanding of Java’s approach to encapsulation. However, since most of the examples in the first part of this book will use this line of code, let’s take a brief look at each part now.

The `public` keyword is an access modifier, which allows the programmer to control the visibility of class members. When a class member is preceded by `public`, then that member may be accessed by code outside the class in which it is declared. (The opposite of `public` is `private`, which prevents a member from being used by code defined outside of its class.) In this case, `main()` must be declared as `public`, since it must be called by code outside of its class when the program is started. The keyword `static` allows `main()` to be called without having to instantiate a particular instance of the class. This is necessary since `main()` is called by the Java Virtual Machine before any objects are made. The keyword `void` simply tells the compiler that `main()` does not return a value. As you will see, methods may also return values. If all this seems a bit confusing, don’t worry. All of these concepts will be discussed in detail in subsequent chapters.

As stated, `main()` is the method called when a Java application begins. Keep in mind that Java is case-sensitive. Thus, `Main` is different from `main`. It is important to understand that the Java compiler will compile classes that do not contain a `main()` method. But `java` has no way to run these classes. So, if you had typed `Main` instead of `main`, the compiler would still compile your program. However, `java` would report an error because it would be unable to find the `main()` method.

Any information that you need to pass to a method is received by variables specified within the set of parentheses that follow the name of the method. These variables are called parameters. If there are no parameters required for a given method, you still need to include the empty parentheses. In `main()`, there is only one parameter, albeit a complicated one. `String args[ ]` declares a parameter named `args`, which is an array of instances of the class `String`. (`Arrays` are collections of similar objects.) Objects of type `String` store character strings. In this case, `args` receives any command-line arguments present when the program is executed. This program does not make use of this information, but other programs shown later in this book will.

The last character on the line is the `. This signals the start of `main()`’s body. All of the code that comprises a method will occur between the method’s opening curly brace and its closing curly brace.

One other point: `main()` is simply a starting place for your program. A complex
program will have dozens of classes, only one of which will need to have a `main()` method to get things started. Furthermore, for some types of programs, you won’t need `main()` at all. However, for most of the programs shown in this book, `main()` is required.

The next line of code is shown here. Notice that it occurs inside `main()`.

```java
System.out.println("This is a simple Java program.");
```

This line outputs the string "This is a simple Java program." followed by a new line on the screen. Output is actually accomplished by the built-in `println()` method. In this case, `println()` displays the string which is passed to it. As you will see, `println()` can be used to display other types of information, too. The line begins with `System.out`. While too complicated to explain in detail at this time, briefly, `System` is a predefined class that provides access to the system, and `out` is the output stream that is connected to the console.

As you have probably guessed, console output (and input) is not used frequently in most real-world Java applications. Since most modern computing environments are graphical in nature, console I/O is used mostly for simple utility programs, demonstration programs, and server-side code. Later in this book, you will learn other ways to generate output using Java. But for now, we will continue to use the console I/O methods.

Notice that the `println()` statement ends with a semicolon. Many statements in Java end with a semicolon. As you will see, the semicolon is an important part of the Java syntax.

The first `}` in the program ends `main()`, and the last `}` ends the `Example` class definition.

**A Second Short Program**

Perhaps no other concept is more fundamental to a programming language than that of a variable. As you may know, a variable is a named memory location that may be assigned a value by your program. The value of a variable may be changed during the execution of the program. The next program shows how a variable is declared and how it is assigned a value. The program also illustrates some new aspects of console output. As the comments at the top of the program state, you should call this file `Example2.java`. 
When you run this program, you will see the following output:

This is num: 100
The value of num * 2 is 200

Let’s take a close look at why this output is generated. The first new line in the program is shown here:

```java
int num; // this declares a variable called num
```

This line declares an integer variable called `num`. Java (like most other languages) requires that variables be declared before they are used.

Following is the general form of a variable declaration:

```java
type var-name;
```

Here, `type` specifies the type of variable being declared, and `var-name` is the name of the variable. If you want to declare more than one variable of the specified type, you may use a comma-separated list of variable names. Java defines several data types, including integer, character, and floating-point. The keyword `int` specifies an integer type.

In the program, the line

```java
num = 100; // this assigns num the value 100
```
assigns to num the value 100. In Java, the assignment operator is a single equal sign.

The next line of code outputs the value of num preceded by the string "This is num:".

```java
System.out.println("This is num: " + num);
```

In this statement, the plus sign causes the value of num to be appended to the string that precedes it, and then the resulting string is output. (Actually, num is first converted from an integer into its string equivalent and then concatenated with the string that precedes it. This process is described in detail later in this book.) This approach can be generalized. Using the + operator, you can join together as many items as you want within a single println() statement.

The next line of code assigns num the value of num times 2. Like most other languages, Java uses the * operator to indicate multiplication. After this line executes, num will contain the value 200.

Here are the next two lines in the program:

```java
System.out.print ("The value of num * 2 is ");
System.out.println (num);
```

Several new things are occurring here. First, the built-in method print() is used to display the string "The value of num * 2 is ". This string is not followed by a newline. This means that when the next output is generated, it will start on the same line. The print() method is just like println(), except that it does not output a newline character after each call. Now look at the call to println(). Notice that num is used by itself. Both print() and println() can be used to output values of any of Java’s built-in types.

## Two Control Statements

Although Chapter 5 will look closely at control statements, two are briefly introduced here so that they can be used in example programs in Chapters 3 and 4. They will also help illustrate an important aspect of Java: blocks of code.

### The if Statement

The Java if statement works much like the IF statement in any other language. It determines the flow of execution based on whether some condition is true or false. Its simplest form is shown here:

```java
if(condition) statement;
```
Here, *condition* is a Boolean expression. (A Boolean expression is one that evaluates to either true or false.) If *condition* is true, then the statement is executed. If *condition* is false, then the statement is bypassed. Here is an example:

```java
if(num < 100) System.out.println("num is less than 100");
```

In this case, if *num* contains a value that is less than 100, the conditional expression is true, and `println()` will execute. If *num* contains a value greater than or equal to 100, then the `println()` method is bypassed.

As you will see in Chapter 4, Java defines a full complement of relational operators which may be used in a conditional expression. Here are a few:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>&lt;</code></td>
<td>Less than</td>
</tr>
<tr>
<td><code>&gt;</code></td>
<td>Greater than</td>
</tr>
<tr>
<td><code>==</code></td>
<td>Equal to</td>
</tr>
</tbody>
</table>

Notice that the test for equality is the double equal sign.

Here is a program that illustrates the *if* statement:
The output generated by this program is shown here:

```
x is less than y
x now equal to y
x now greater than y
```

Notice one other thing in this program. The line

```
int x, y;
```

declares two variables, x and y, by use of a comma-separated list.

**The for Loop**

Loop statements are an important part of nearly any programming language because they provide a way to repeatedly execute some task. As you will see in Chapter 5, Java supplies a powerful assortment of loop constructs. Perhaps the most versatile is the **for** loop. The simplest form of the **for** loop is shown here:

```
for(initialization; condition; iteration) statement;
```
In its most common form, the *initialization* portion of the loop sets a loop control variable to an initial value. The *condition* is a Boolean expression that tests the loop control variable. If the outcome of that test is true, *statement* executes and the **for** loop continues to iterate. If it is false, the loop terminates. The *iteration* expression determines how the loop control variable is changed each time the loop iterates. Here is a short program that illustrates the **for** loop:

```java
/*
   Demonstrate the for loop.
   Call this file "ForTest.java".
*/
class ForTest {
   public static void main(String args[]) {
      int x;

      for(x = 0; x<10; x = x+1)
         System.out.println("This is x: " + x);
   }
}
```

This program generates the following output:

```
This is x: 0
This is x: 1
This is x: 2
This is x: 3
This is x: 4
This is x: 5
This is x: 6
This is x: 7
This is x: 8
This is x: 9
```

In this example, `x` is the loop control variable. It is initialized to zero in the initialization portion of the **for**. At the start of each iteration (including the first one), the conditional test `x < 10` is performed. If the outcome of this test is true, the `println()` statement is executed, and then the iteration portion of the loop is executed, which increases `x` by 1. This process continues until the conditional test is false.

As a point of interest, in professionally written Java programs you will almost never see the iteration portion of the loop written as shown in the preceding program. That is, you will seldom see statements like this:
The reason is that Java includes a special increment operator which performs this operation more efficiently. The increment operator is `++`. (That is, two plus signs back to back.) The increment operator increases its operand by one. By use of the increment operator, the preceding statement can be written like this:

\[ x++ \]

Thus, the `for` in the preceding program will usually be written like this:

```java
for(x = 0; x<10; x++)
```

You might want to try this. As you will see, the loop still runs exactly the same as it did before.

Java also provides a decrement operator, which is specified as `--`. This operator decreases its operand by one.

### Using Blocks of Code

Java allows two or more statements to be grouped into *blocks of code*, also called *code blocks*. This is done by enclosing the statements between opening and closing curly braces. Once a block of code has been created, it becomes a logical unit that can be used any place that a single statement can. For example, a block can be a target for Java’s `if` and `for` statements. Consider this `if` statement:

```java
if(x < y) { // begin a block
    x = y;
    y = 0;
} // end of block
```

Here, if \( x \) is less than \( y \), then both statements inside the block will be executed. Thus, the two statements inside the block form a logical unit, and one statement cannot execute without the other also executing. The key point here is that whenever you need to logically link two or more statements, you do so by creating a block.

Let’s look at another example. The following program uses a block of code as the target of a `for` loop.
Demonstrate a block of code.

Call this file "BlockTest.java"

```java
class BlockTest {
    public static void main(String args[]) {
        int x, y;

        y = 20;

        // the target of this loop is a block
        for(x = 0; x<10; x++) {
            System.out.println("This is x: "+x);
            System.out.println("This is y: "+y);
            y = y - 2;
        }
    }
}
```

The output generated by this program is shown here:

This is x: 0
This is y: 20
This is x: 1
This is y: 18
This is x: 2
This is y: 16
This is x: 3
This is y: 14
This is x: 4
This is y: 12
This is x: 5
This is y: 10
This is x: 6
This is y: 8
This is x: 7
This is y: 6
This is x: 8
This is y: 4
This is x: 9
This is y: 2

In this case, the target of the `for` loop is a block of code and not just a single statement. Thus, each time the loop iterates, the three statements inside the block will
be executed. This fact is, of course, evidenced by the output generated by the program.

As you will see later in this book, blocks of code have additional properties and uses. However, the main reason for their existence is to create logically inseparable units of code.

## Lexical Issues

Now that you have seen several short Java programs, it is time to more formally describe the atomic elements of Java. Java programs are a collection of whitespace, identifiers, literals, comments, operators, separators, and keywords. The operators are described in the next chapter. The others are described next.

### Whitespace

Java is a free-form language. This means that you do not need to follow any special indentation rules. For instance, the Example program could have been written all on one line or in any other strange way you felt like typing it, as long as there was at least one whitespace character between each token that was not already delineated by an operator or separator. In Java, whitespace is a space, tab, newline, or form feed.

### Identifiers

Identifiers are used to name things, such as classes, variables, and methods. An identifier may be any descriptive sequence of uppercase and lowercase letters, numbers, or the underscore and dollar-sign characters. (The dollar-sign character is not intended for general use.) They must not begin with a number, lest they be confused with a numeric literal. Again, Java is case-sensitive, so VALUE is a different identifier than Value. Some examples of valid identifiers are

<table>
<thead>
<tr>
<th>AvgTemp</th>
<th>count</th>
<th>a4</th>
<th>$test</th>
<th>this_is_ok</th>
</tr>
</thead>
</table>

Invalid identifier names include these:

<table>
<thead>
<tr>
<th>2count</th>
<th>high-temp</th>
<th>Not/ok</th>
</tr>
</thead>
</table>

**NOTE** Beginning with JDK 9, the underscore cannot be used by itself as an identifier.
**Literals**

A constant value in Java is created by using a *literal* representation of it. For example, here are some literals:

| 100 | 98.6 | ‘X’ | “This is a test” |

Left to right, the first literal specifies an integer, the next is a floating-point value, the third is a character constant, and the last is a string. A literal can be used anywhere a value of its type is allowed.

**Comments**

As mentioned, there are three types of comments defined by Java. You have already seen two: single-line and multiline. The third type is called a *documentation comment*. This type of comment is used to produce an HTML file that documents your program. The documentation comment begins with a /** and ends with a */. Documentation comments are explained in Appendix A.

**Separators**

In Java, there are a few characters that are used as separators. The most commonly used separator in Java is the semicolon. As you have seen, it is often used to terminate statements. The separators are shown in the following table:
The Java Keywords

There are 61 keywords currently defined in the Java language (see Table 2-1). These keywords, combined with the syntax of the operators and separators, form the foundation of the Java language. In general, these keywords cannot be used as identifiers, meaning that they cannot be used as names for a variable, class, or method. The exceptions to this rule are the new context-sensitive keywords added by JDK 9 to support modules. (See Chapter 16 for details.) Also, beginning with JDK 9, an underscore by itself is considered a keyword in order to prevent its use as the name of something in your program.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>()</td>
<td>Parentheses</td>
<td>Used to contain lists of parameters in method definition and invocation. Also used for defining precedence in expressions, containing expressions in control statements, and surrounding cast types.</td>
</tr>
<tr>
<td>{}</td>
<td>Braces</td>
<td>Used to contain the values of automatically initialized arrays. Also used to define a block of code, for classes, methods, and local scopes.</td>
</tr>
<tr>
<td>[]</td>
<td>Brackets</td>
<td>Used to declare array types. Also used when dereferencing array values.</td>
</tr>
<tr>
<td>;</td>
<td>Semicolon</td>
<td>Terminates statements.</td>
</tr>
<tr>
<td>,</td>
<td>Comma</td>
<td>Separates consecutive identifiers in a variable declaration. Also used to chain statements together inside a for statement.</td>
</tr>
<tr>
<td>.</td>
<td>Period</td>
<td>Used to separate package names from subpackages and classes. Also used to separate a variable or method from a reference variable.</td>
</tr>
<tr>
<td>::</td>
<td>Colons</td>
<td>Used to create a method or constructor reference.</td>
</tr>
<tr>
<td>...</td>
<td>Ellipsis</td>
<td>Indicates a variable-arity parameter.</td>
</tr>
<tr>
<td>@</td>
<td>Ampersand</td>
<td>Begins an annotation.</td>
</tr>
</tbody>
</table>
The keywords **const** and **goto** are reserved but not used. In the early days of Java, several other keywords were reserved for possible future use. However, the current specification for Java defines only the keywords shown in Table 2-1.

In addition to the keywords, Java reserves the following: **true**, **false**, and **null**. These are values defined by Java. You may not use these words for the names of variables, classes, and so on.

### The Java Class Libraries

The sample programs shown in this chapter make use of two of Java’s built-in methods: **println()** and **print()**. As mentioned, these methods are available through `System.out`. **System** is a class predefined by Java that is automatically included in your programs. In the larger view, the Java environment relies on several built-in class libraries that contain many built-in methods that provide support for such things as I/O, string handling, networking, and graphics. The standard classes also provide support for a graphical user interface (GUI). Thus, Java as a totality is a combination of the Java language itself, plus its standard classes. As you will see, the class libraries provide much of the functionality that comes with Java. Indeed, part of becoming a Java programmer is learning to use the standard Java classes.

Throughout Part I of this book, various elements of the standard library classes and methods are described as needed. In Part II, several class libraries are described in detail. An Overview of Java
CHAPTER
This chapter examines three of Java’s most fundamental elements: data types, variables, and arrays. As with all modern programming languages, Java supports several types of data. You may use these types to declare variables and to create arrays. As you will see, Java’s approach to these items is clean, efficient, and cohesive.

Java Is a Strongly Typed Language

It is important to state at the outset that Java is a strongly typed language. Indeed, part of Java’s safety and robustness comes from this fact. Let’s see what this means. First, every variable has a type, every expression has a type, and every type is strictly defined. Second, all assignments, whether explicit or via parameter passing in method calls, are checked for type compatibility. There are no automatic coercions or conversions of conflicting types as in some languages. The Java compiler checks all expressions and parameters to ensure that the types are compatible. Any type mismatches are errors that must be corrected before the compiler will finish compiling the class.

The Primitive Types

Java defines eight primitive types of data: byte, short, int, long, char, float, double, and boolean. The primitive types are also commonly referred to as simple types, and both terms will be used in this book. These can be put in four groups:

- **Integers** This group includes byte, short, int, and long, which are for whole-valued signed numbers.
- **Floating-point numbers** This group includes float and double, which represent numbers with fractional precision.
- **Characters** This group includes char, which represents symbols in a character set, like letters and numbers.
- **Boolean** This group includes boolean, which is a special type for representing true/false values.

You can use these types as-is, or to construct arrays or your own class types. Thus,
they form the basis for all other types of data that you can create.

The primitive types represent single values—not complex objects. Although Java is otherwise completely object-oriented, the primitive types are not. They are analogous to the simple types found in most other non–object-oriented languages. The reason for this is efficiency. Making the primitive types into objects would have degraded performance too much.

The primitive types are defined to have an explicit range and mathematical behavior. Languages such as C and C++ allow the size of an integer to vary based upon the dictates of the execution environment. However, Java is different. Because of Java’s portability requirement, all data types have a strictly defined range. For example, an int is always 32 bits, regardless of the particular platform. This allows programs to be written that are guaranteed to run without porting on any machine architecture. While strictly specifying the size of an integer may cause a small loss of performance in some environments, it is necessary in order to achieve portability.

Let’s look at each type of data in turn.

**Integers**

Java defines four integer types: byte, short, int, and long. All of these are signed, positive and negative values. Java does not support unsigned, positive-only integers. Many other computer languages support both signed and unsigned integers. However, Java’s designers felt that unsigned integers were unnecessary. Specifically, they felt that the concept of unsigned was used mostly to specify the behavior of the high-order bit, which defines the sign of an integer value. As you will see in Chapter 4, Java manages the meaning of the high-order bit differently, by adding a special “unsigned right shift” operator. Thus, the need for an unsigned integer type was eliminated.

The width of an integer type should not be thought of as the amount of storage it consumes, but rather as the behavior it defines for variables and expressions of that type. The Java run-time environment is free to use whatever size it wants, as long as the types behave as you declared them. The width and ranges of these integer types vary widely, as shown in this table:

<table>
<thead>
<tr>
<th>Name</th>
<th>Width</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>long</td>
<td>64</td>
<td>−9,223,372,036,854,775,808 to 9,223,372,036,854,775,807</td>
</tr>
<tr>
<td>int</td>
<td>32</td>
<td>−2,147,483,648 to 2,147,483,647</td>
</tr>
<tr>
<td>short</td>
<td>16</td>
<td>−32,768 to 32,767</td>
</tr>
<tr>
<td>byte</td>
<td>8</td>
<td>−128 to 127</td>
</tr>
</tbody>
</table>
Let’s look at each type of integer.

**byte**

The smallest integer type is byte. This is a signed 8-bit type that has a range from –128 to 127. Variables of type byte are especially useful when you’re working with a stream of data from a network or file. They are also useful when you’re working with raw binary data that may not be directly compatible with Java’s other built-in types.

Byte variables are declared by use of the byte keyword. For example, the following declares two byte variables called b and c:

```java
byte b, c;
```

**short**

short is a signed 16-bit type. It has a range from –32,768 to 32,767. It is probably the least-used Java type. Here are some examples of short variable declarations:

```java
short s;
short t;
```

**int**

The most commonly used integer type is int. It is a signed 32-bit type that has a range from –2,147,483,648 to 2,147,483,647. In addition to other uses, variables of type int are commonly employed to control loops and to index arrays. Although you might think that using a byte or short would be more efficient than using an int in situations in which the larger range of an int is not needed, this may not be the case. The reason is that when byte and short values are used in an expression, they are promoted to int when the expression is evaluated. (Type promotion is described later in this chapter.) Therefore, int is often the best choice when an integer is needed.

**long**

long is a signed 64-bit type and is useful for those occasions where an int type is not large enough to hold the desired value. The range of a long is quite large. This makes it useful when big, whole numbers are needed. For example, here is a program that computes the number of miles that light will travel in a specified number of days:
This program generates the following output:

    In 1000 days light will travel about 1607040000000000 miles.

Clearly, the result could not have been held in an int variable.

Floating-Point Types

Floating-point numbers, also known as real numbers, are used when evaluating expressions that require fractional precision. For example, calculations such as square root, or transcendentials such as sine and cosine, result in a value whose precision requires a floating-point type. Java implements the standard (IEEE–754) set of floating-point types and operators. There are two kinds of floating-point types, float and double, which represent single- and double-precision numbers, respectively. Their width and ranges are shown here:

<table>
<thead>
<tr>
<th>Name</th>
<th>Width in Bits</th>
<th>Approximate Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>double</td>
<td>64</td>
<td>4.9e–324 to 1.8e+308</td>
</tr>
<tr>
<td>float</td>
<td>32</td>
<td>1.4e–045 to 3.4e+038</td>
</tr>
</tbody>
</table>
Each of these floating-point types is examined next.

**float**

The type `float` specifies a *single-precision* value that uses 32 bits of storage. Single precision is faster on some processors and takes half as much space as double precision, but will become imprecise when the values are either very large or very small. Variables of type `float` are useful when you need a fractional component, but don’t require a large degree of precision. For example, `float` can be useful when representing dollars and cents.

Here are some example `float` variable declarations:

```java
float hightemp, lowtemp;
```

**double**

Double precision, as denoted by the `double` keyword, uses 64 bits to store a value. Double precision is actually faster than single precision on some modern processors that have been optimized for high-speed mathematical calculations. All transcendental math functions, such as `sin()`, `cos()`, and `sqrt()`, return `double` values. When you need to maintain accuracy over many iterative calculations, or are manipulating large-valued numbers, `double` is the best choice.

Here is a short program that uses `double` variables to compute the area of a circle:

```java
// Compute the area of a circle.
class Area {
    public static void main(String args[]) {
        double pi, r, a;
        r = 10.8; // radius of circle
        pi = 3.1416; // pi, approximately
        a = pi * r * r; // compute area

        System.out.println("Area of circle is "+ a);
    }
}
```

**Characters**

In Java, the data type used to store characters is `char`. A key point to understand is that Java uses *Unicode* to represent characters. Unicode defines a fully international character set that can represent all of the characters found in all human languages. It is a unification of dozens of character sets, such as Latin, Greek, Arabic, Cyrillic,
Hebrew, Katakana, Hangul, and many more. At the time of Java's creation, Unicode required 16 bits. Thus, in Java **char** is a 16-bit type. The range of a **char** is 0 to 65,536. There are no negative **chars**. The standard set of characters known as ASCII still ranges from 0 to 127 as always, and the extended 8-bit character set, ISO-Latin-1, ranges from 0 to 255. Since Java is designed to allow programs to be written for worldwide use, it makes sense that it would use Unicode to represent characters. Of course, the use of Unicode is somewhat inefficient for languages such as English, German, Spanish, or French, whose characters can easily be contained within 8 bits. But such is the price that must be paid for global portability.

**NOTE** More information about Unicode can be found at [http://www.unicode.org](http://www.unicode.org).

Here is a program that demonstrates **char** variables:

```java
// Demonstrate char data type.
class CharDemo {
    public static void main(String args[]) {
        char ch1, ch2;

        ch1 = 88; // code for X
        ch2 = 'Y';

        System.out.print("ch1 and ch2: ");
        System.out.println(ch1 + " " + ch2);
    }
}
```

This program displays the following output:

```
ch1 and ch2: X Y
```

Notice that **ch1** is assigned the value 88, which is the ASCII (and Unicode) value that corresponds to the letter X. As mentioned, the ASCII character set occupies the first 127 values in the Unicode character set. For this reason, all the “old tricks” that you may have used with characters in other languages will work in Java, too.

Although **char** is designed to hold Unicode characters, it can also be used as an integer type on which you can perform arithmetic operations. For example, you can add two characters together, or increment the value of a character variable. Consider the following program:
The output generated by this program is shown here:

ch1 contains X
ch1 is now Y

In the program, ch1 is first given the value X. Next, ch1 is incremented. This results in ch1 containing Y, the next character in the ASCII (and Unicode) sequence.

NOTE In the formal specification for Java, char is referred to as an integral type, which means that it is in the same general category as int, short, long, and byte. However, because its principal use is for representing Unicode characters, char is commonly considered to be in a category of its own.

**Booleans**

Java has a primitive type, called boolean, for logical values. It can have only one of two possible values, true or false. This is the type returned by all relational operators, as in the case of a < b. boolean is also the type required by the conditional expressions that govern the control statements such as if and for.

Here is a program that demonstrates the boolean type:
// Demonstrate boolean values.
class BoolTest {
    public static void main(String args[]) {
        boolean b;

        b = false;
        System.out.println("b is " + b);
        b = true;
        System.out.println("b is " + b);

        // a boolean value can control the if statement
        if(b) System.out.println("This is executed.");

        b = false;
        if(b) System.out.println("This is not executed.");

        // outcome of a relational operator is a boolean value
        System.out.println("10 > 9 is " + (10 > 9));
    }
}

The output generated by this program is shown here:

b is false
b is true
  This is executed.
10 > 9 is true

There are three interesting things to notice about this program. First, as you can see, when a boolean value is output by println(), "true" or "false" is displayed. Second, the value of a boolean variable is sufficient, by itself, to control the if statement. There is no need to write an if statement like this:

if(b == true) ...

Third, the outcome of a relational operator, such as <, is a boolean value. This is why the expression 10>9 displays the value "true." Further, the extra set of parentheses around 10>9 is necessary because the + operator has a higher precedence than the >.

A Closer Look at Literals
Literals were mentioned briefly in Chapter 2. Now that the built-in types have been
formally described, let’s take a closer look at them.

**Integer Literals**

Integers are probably the most commonly used type in the typical program. Any whole number value is an integer literal. Examples are 1, 2, 3, and 42. These are all decimal values, meaning they are describing a base 10 number. Two other bases that can be used in integer literals are octal (base eight) and hexadecimal (base 16). Octal values are denoted in Java by a leading zero. Normal decimal numbers cannot have a leading zero. Thus, the seemingly valid value 09 will produce an error from the compiler, since 9 is outside of octal’s 0 to 7 range. A more common base for numbers used by programmers is hexadecimal, which matches cleanly with modulo 8 word sizes, such as 8, 16, 32, and 64 bits. You signify a hexadecimal constant with a leading zero-x, (0x or 0X). The range of a hexadecimal digit is 0 to 15, so A through F (or a through f) are substituted for 10 through 15.

Integer literals create an int value, which in Java is a 32-bit integer value. Since Java is strongly typed, you might be wondering how it is possible to assign an integer literal to one of Java’s other integer types, such as byte or long, without causing a type mismatch error. Fortunately, such situations are easily handled. When a literal value is assigned to a byte or short variable, no error is generated if the literal value is within the range of the target type. An integer literal can always be assigned to a long variable. However, to specify a long literal, you will need to explicitly tell the compiler that the literal value is of type long. You do this by appending an upper- or lowercase L to the literal. For example, 0x7fffffffffffffffL or 9223372036854775807L is the largest long. An integer can also be assigned to a char as long as it is within range.

Beginning with JDK 7, you can also specify integer literals using binary. To do so, prefix the value with 0b or 0B. For example, this specifies the decimal value 10 using a binary literal:

```java
int x = 0b1010;
```

Among other uses, the addition of binary literals makes it easier to enter values used as bitmasks. In such a case, the decimal (or hexadecimal) representation of the value does not visually convey its meaning relative to its use. The binary literal does.

Also beginning with JDK 7, you can embed one or more underscores in an integer literal. Doing so makes it easier to read large integer literals. When the literal is compiled, the underscores are discarded. For example, given

```java
int x = 123_456_789;
```
the value given to `x` will be 123,456,789. The underscores will be ignored. Underscores can only be used to separate digits. They cannot come at the beginning or the end of a literal. It is, however, permissible for more than one underscore to be used between two digits. For example, this is valid:

```java
int x = 123__456__789;
```

The use of underscores in an integer literal is especially useful when encoding such things as telephone numbers, customer ID numbers, part numbers, and so on. They are also useful for providing visual groupings when specifying binary literals. For example, binary values are often visually grouped in four-digits units, as shown here:

```java
int x = 0b1101_0101_0001_1010;
```

**Floating-Point Literals**

Floating-point numbers represent decimal values with a fractional component. They can be expressed in either standard or scientific notation. *Standard notation* consists of a whole number component followed by a decimal point followed by a fractional component. For example, 2.0, 3.14159, and 0.6667 represent valid standard-notation floating-point numbers. *Scientific notation* uses a standard-notation, floating-point number plus a suffix that specifies a power of 10 by which the number is to be multiplied. The exponent is indicated by an `E` or `e` followed by a decimal number, which can be positive or negative. Examples include 6.022E23, 314159E–05, and 2e+100.

Floating-point literals in Java default to `double` precision. To specify a `float` literal, you must append an `F` or `f` to the constant. You can also explicitly specify a `double` literal by appending a `D` or `d`. Doing so is, of course, redundant. The default `double` type consumes 64 bits of storage, while the smaller `float` type requires only 32 bits.

Hexadecimal floating-point literals are also supported, but they are rarely used. They must be in a form similar to scientific notation, but a `P` or `p`, rather than an `E` or `e`, is used. For example, `0x12.2P2` is a valid floating-point literal. The value following the `P`, called the *binary exponent*, indicates the power-of-two by which the number is multiplied. Therefore, `0x12.2P2` represents 72.5.

Beginning with JDK 7, you can embed one or more underscores in a floating-point literal. This feature works the same as it does for integer literals, which were just described. Its purpose is to make it easier to read large floating-point literals. When the literal is compiled, the underscores are discarded. For example, given
double num = 9_423_497_862.0;

the value given to num will be 9,423,497,862.0. The underscores will be ignored. As
is the case with integer literals, underscores can only be used to separate digits. They
cannot come at the beginning or the end of a literal. It is, however, permissible for
more than one underscore to be used between two digits. It is also permissible to use
underscores in the fractional portion of the number. For example,

double num = 9_423_497.1_0_9;

is legal. In this case, the fractional part is .109.

**Boolean Literals**

Boolean literals are simple. There are only two logical values that a boolean value
can have, **true** and **false**. The values of **true** and **false** do not convert into any
numerical representation. The **true** literal in Java does not equal 1, nor does the **false**
literal equal 0. In Java, the Boolean literals can only be assigned to variables
declared as **boolean** or used in expressions with Boolean operators.

**Character Literals**

Characters in Java are indices into the Unicode character set. They are 16-bit values
that can be converted into integers and manipulated with the integer operators, such
as the addition and subtraction operators. A literal character is represented inside a
pair of single quotes. All of the visible ASCII characters can be directly entered
inside the quotes, such as 'a', 'z', and '@'. For characters that are impossible to enter
directly, there are several escape sequences that allow you to enter the character you
need, such as '\' for the single-quote character itself and '\n' for the newline
character. There is also a mechanism for directly entering the value of a character in
octal or hexadecimal. For octal notation, use the backslash followed by the three-
digit number. For example, '\141' is the letter 'a'. For hexadecimal, you enter a
backslash-u (\u), then exactly four hexadecimal digits. For example, '\u0061' is the
ISO-Latin-1 'a' because the top byte is zero. '\ua432' is a Japanese Katakana
character. Table 3-1 shows the character escape sequences.
Table 3-1  Character Escape Sequences

<table>
<thead>
<tr>
<th>Escape Sequence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>\ddd</td>
<td>Octal character (ddd)</td>
</tr>
<tr>
<td>\uxxxx</td>
<td>Hexadecimal Unicode character (xxxx)</td>
</tr>
<tr>
<td>\</td>
<td>Single quote</td>
</tr>
<tr>
<td>&quot;</td>
<td>Double quote</td>
</tr>
<tr>
<td>\</td>
<td>Backslash</td>
</tr>
<tr>
<td>\r</td>
<td>Carriage return</td>
</tr>
<tr>
<td>\n</td>
<td>New line (also known as line feed)</td>
</tr>
<tr>
<td>\f</td>
<td>Form feed</td>
</tr>
<tr>
<td>\t</td>
<td>Tab</td>
</tr>
<tr>
<td>\b</td>
<td>Backspace</td>
</tr>
</tbody>
</table>

String Literals

String literals in Java are specified like they are in most other languages—by enclosing a sequence of characters between a pair of double quotes. Examples of string literals are

"Hello World"
"two\nlines"
" "This is in quotes"""

The escape sequences and octal/hexadecimal notations that were defined for character literals work the same way inside of string literals. One important thing to note about Java strings is that they must begin and end on the same line. There is no line-continuation escape sequence as there is in some other languages.

NOTE  As you may know, in some other languages strings are implemented as arrays of characters. However, this is not the case in Java. Strings are actually object types. As you will see later in this book, because Java implements strings as objects, Java includes extensive string-handling capabilities that are both powerful and easy to use.

Variables

The variable is the basic unit of storage in a Java program. A variable is defined by
the combination of an identifier, a type, and an optional initializer. In addition, all
variables have a scope, which defines their visibility, and a lifetime. These elements
are examined next.

Declaring a Variable

In Java, all variables must be declared before they can be used. The basic form of a
variable declaration is shown here:

\[
\text{type identifier } [= \text{value }] [, \text{identifier } [=\text{value }] \ldots];
\]

Here, \text{type} is one of Java’s atomic types, or the name of a class or interface. (Class
and interface types are discussed later in Part I of this book.) The \text{identifier} is the
name of the variable. You can initialize the variable by specifying an equal sign and
a value. Keep in mind that the initialization expression must result in a value of the
same (or compatible) type as that specified for the variable. To declare more than
one variable of the specified type, use a comma-separated list.

Here are several examples of variable declarations of various types. Note that
some include an initialization.

\begin{verbatim}
int a, b, c;         // declares three ints, a, b, and c.
int d = 3, e, f = 5; // declares three more ints, initializing
                      // d and f.
byte z = 22;         // initializes z.
double pi = 3.14159; // declares an approximation of pi.
char x = 'x';        // the variable x has the value 'x'.
\end{verbatim}

The identifiers that you choose have nothing intrinsic in their names that indicates
their type. Java allows any properly formed identifier to have any declared type.

Dynamic Initialization

Although the preceding examples have used only constants as initializers, Java
allows variables to be initialized dynamically, using any expression valid at the time
the variable is declared.

For example, here is a short program that computes the length of the hypotenuse
of a right triangle given the lengths of its two opposing sides:
Here, three local variables—\(a\), \(b\), and \(c\)—are declared. The first two, \(a\) and \(b\), are initialized by constants. However, \(c\) is initialized dynamically to the length of the hypotenuse (using the Pythagorean theorem). The program uses another of Java’s built-in methods, \(\text{sqrt}(\ ))\), which is a member of the \(\text{Math}\) class, to compute the square root of its argument. The key point here is that the initialization expression may use any element valid at the time of the initialization, including calls to methods, other variables, or literals.

### The Scope and Lifetime of Variables

So far, all of the variables used have been declared at the start of the \(\text{main}(\ )\) method. However, Java allows variables to be declared within any block. As explained in Chapter 2, a block is begun with an opening curly brace and ended by a closing curly brace. A block defines a scope. Thus, each time you start a new block, you are creating a new scope. A scope determines what objects are visible to other parts of your program. It also determines the lifetime of those objects.

Many other computer languages define two general categories of scopes: global and local. However, these traditional scopes do not fit well with Java’s strict, object-oriented model. While it is possible to create what amounts to being a global scope, it is by far the exception, not the rule. In Java, the two major scopes are those defined by a class and those defined by a method. Even this distinction is somewhat artificial. However, since the class scope has several unique properties and attributes that do not apply to the scope defined by a method, this distinction makes some sense. Because of the differences, a discussion of class scope (and variables declared within it) is deferred until Chapter 6, when classes are described. For now, we will only examine the scopes defined by or within a method.

The scope defined by a method begins with its opening curly brace. However, if that method has parameters, they too are included within the method’s scope. Although this book will look more closely at parameters in Chapter 6, for the sake of
this discussion, they work the same as any other method variable.

As a general rule, variables declared inside a scope are not visible (that is, accessible) to code that is defined outside that scope. Thus, when you declare a variable within a scope, you are localizing that variable and protecting it from unauthorized access and/or modification. Indeed, the scope rules provide the foundation for encapsulation.

Scopes can be nested. For example, each time you create a block of code, you are creating a new, nested scope. When this occurs, the outer scope encloses the inner scope. This means that objects declared in the outer scope will be visible to code within the inner scope. However, the reverse is not true. Objects declared within the inner scope will not be visible outside it.

To understand the effect of nested scopes, consider the following program:

```java
// Demonstrate block scope.
class Scope {
    public static void main(String args[]) {
        int x; // known to all code within main

        x = 10;
        if(x == 10) { // start new scope
            int y = 20; // known only to this block

            // x and y both known here.
            System.out.println("x and y: "+x+" "+y);
            x = y * 2;
        }
        // y = 100; // Error! y not known here

        // x is still known here.
        System.out.println("x is "+x);
    }
}
```

As the comments indicate, the variable `x` is declared at the start of `main()`’s scope and is accessible to all subsequent code within `main()`. Within the `if` block, `y` is declared. Since a block defines a scope, `y` is only visible to other code within its block. This is why outside of its block, the line `y = 100;` is commented out. If you remove the leading comment symbol, a compile-time error will occur, because `y` is not visible outside of its block. Within the `if` block, `x` can be used because code within a block (that is, a nested scope) has access to variables declared by an enclosing scope.

Within a block, variables can be declared at any point, but are valid only after
they are declared. Thus, if you define a variable at the start of a method, it is available to all of the code within that method. Conversely, if you declare a variable at the end of a block, it is effectively useless, because no code will have access to it. For example, this fragment is invalid because `count` cannot be used prior to its declaration:

```java
// This fragment is wrong!
count = 100; // oops! cannot use count before it is declared!
int count;
```

Here is another important point to remember: variables are created when their scope is entered, and destroyed when their scope is left. This means that a variable will not hold its value once it has gone out of scope. Therefore, variables declared within a method will not hold their values between calls to that method. Also, a variable declared within a block will lose its value when the block is left. Thus, the lifetime of a variable is confined to its scope.

If a variable declaration includes an initializer, then that variable will be reinitialized each time the block in which it is declared is entered. For example, consider the next program:

```java
// Demonstrate lifetime of a variable.
class LifeTime {
    public static void main(String args[]) {
        int x;

        for(x = 0; x < 3; x++) {
            int y = -1; // y is initialized each time block is entered
            System.out.println("y is: "+ y); // this always prints -1
            y = 100;
            System.out.println("y is now: "+ y);
        }
    }
}
```

The output generated by this program is shown here:

```
y is: -1
y is now: 100
y is: -1
y is now: 100
y is: -1
y is now: 100
```
As you can see, \( y \) is reinitialized to \(-1\) each time the inner \texttt{for} loop is entered. Even though it is subsequently assigned the value \(100\), this value is lost.

One last point: Although blocks can be nested, you cannot declare a variable to have the same name as one in an outer scope. For example, the following program is illegal:

```java
// This program will not compile
class ScopeErr {  
   public static void main(String args[]) {  
      int bar = 1;
      {  
         // creates a new scope
         int bar = 2;  // Compile-time error - bar already defined!
      }
   }
}
```

**Type Conversion and Casting**

If you have previous programming experience, then you already know that it is fairly common to assign a value of one type to a variable of another type. If the two types are compatible, then Java will perform the conversion automatically. For example, it is always possible to assign an \texttt{int} value to a \texttt{long} variable. However, not all types are compatible, and thus, not all type conversions are implicitly allowed. For instance, there is no automatic conversion defined from \texttt{double} to \texttt{byte}. Fortunately, it is still possible to obtain a conversion between incompatible types. To do so, you must use a \textit{cast}, which performs an explicit conversion between incompatible types. Let’s look at both automatic type conversions and casting.

**Java’s Automatic Conversions**

When one type of data is assigned to another type of variable, an \textit{automatic type conversion} will take place if the following two conditions are met:

- The two types are compatible.
- The destination type is larger than the source type.

When these two conditions are met, a \textit{widening conversion} takes place. For example, the \texttt{int} type is always large enough to hold all valid \texttt{byte} values, so no explicit cast statement is required.

For widening conversions, the numeric types, including integer and floating-point types, are compatible with each other. However, there are no automatic conversions
from the numeric types to char or boolean. Also, char and boolean are not compatible with each other.

As mentioned earlier, Java also performs an automatic type conversion when storing a literal integer constant into variables of type byte, short, long, or char.

**Casting Incompatible Types**

Although the automatic type conversions are helpful, they will not fulfill all needs. For example, what if you want to assign an int value to a byte variable? This conversion will not be performed automatically, because a byte is smaller than an int. This kind of conversion is sometimes called a narrowing conversion, since you are explicitly making the value narrower so that it will fit into the target type.

To create a conversion between two incompatible types, you must use a cast. A cast is simply an explicit type conversion. It has this general form:

```
(target-type) value
```

Here, target-type specifies the desired type to convert the specified value to. For example, the following fragment casts an int to a byte. If the integer’s value is larger than the range of a byte, it will be reduced modulo (the remainder of an integer division by the) byte’s range.

```java
int a;
byte b;
// ...
b = (byte) a;
```

A different type of conversion will occur when a floating-point value is assigned to an integer type: truncation. As you know, integers do not have fractional components. Thus, when a floating-point value is assigned to an integer type, the fractional component is lost. For example, if the value 1.23 is assigned to an integer, the resulting value will simply be 1. The 0.23 will have been truncated. Of course, if the size of the whole number component is too large to fit into the target integer type, then that value will be reduced modulo the target type’s range.

The following program demonstrates some type conversions that require casts:
This program generates the following output:

Conversion of int to byte.
i and b 257 1

Conversion of double to int.
d and i 323.142 323

Conversion of double to byte.
d and b 323.142 67

Let’s look at each conversion. When the value 257 is cast into a byte variable, the result is the remainder of the division of 257 by 256 (the range of a byte), which is 1 in this case. When the d is converted to an int, its fractional component is lost. When d is converted to a byte, its fractional component is lost, and the value is reduced modulo 256, which in this case is 67.

Automatic Type Promotion in Expressions
In addition to assignments, there is another place where certain type conversions may occur: in expressions. To see why, consider the following. In an expression, the precision required of an intermediate value will sometimes exceed the range of either
operand. For example, examine the following expression:

```java
byte a = 40;
byte b = 50;
byte c = 100;
int d = a * b / c;
```

The result of the intermediate term \(a \times b\) easily exceeds the range of either of its `byte` operands. To handle this kind of problem, Java automatically promotes each `byte`, `short`, or `char` operand to `int` when evaluating an expression. This means that the subexpression \(a \times b\) is performed using integers—not bytes. Thus, 2,000, the result of the intermediate expression, \(50 \times 40\), is legal even though \(a\) and \(b\) are both specified as type `byte`.

As useful as the automatic promotions are, they can cause confusing compile-time errors. For example, this seemingly correct code causes a problem:

```java
byte b = 50;
b = b * 2; // Error! Cannot assign an int to a byte!
```

The code is attempting to store \(50 \times 2\), a perfectly valid `byte` value, back into a `byte` variable. However, because the operands were automatically promoted to `int` when the expression was evaluated, the result has also been promoted to `int`. Thus, the result of the expression is now of type `int`, which cannot be assigned to a `byte` without the use of a cast. This is true even if, as in this particular case, the value being assigned would still fit in the target type.

In cases where you understand the consequences of overflow, you should use an explicit cast, such as

```java
byte b = 50;
b = (byte)(b * 2);
```

which yields the correct value of 100.

**The Type Promotion Rules**

Java defines several *type promotion* rules that apply to expressions. They are as follows: First, all `byte`, `short`, and `char` values are promoted to `int`, as just described. Then, if one operand is a `long`, the whole expression is promoted to `long`. If one operand is a `float`, the entire expression is promoted to `float`. If any of the operands are `double`, the result is `double`.

The following program demonstrates how each value in the expression gets promoted to match the second argument to each binary operator:
class Promote {
    public static void main(String args[]) {
        byte b = 42;
        char c = 'a';
        short s = 1024;
        int i = 50000;
        float f = 5.67f;
        double d = .1234;
        double result = (f * b) + (i / c) - (d * s);
        System.out.println((f * b) + " + " + (i / c) + " - " + (d * s));
        System.out.println("result = " + result);
    }
}

Let’s look closely at the type promotions that occur in this line from the program:

double result = (f * b) + (i / c) - (d * s);

In the first subexpression, \( f \times b \), \( b \) is promoted to a \textit{float} and the result of the subexpression is \textit{float}. Next, in the subexpression \( i/c \), \( c \) is promoted to \textit{int}, and the result is of type \textit{int}. Then, in \( d \times s \), the value of \( s \) is promoted to \textit{double}, and the type of the subexpression is \textit{double}. Finally, these three intermediate values, \textit{float}, \textit{int}, and \textit{double}, are considered. The outcome of \textit{float} plus an \textit{int} is a \textit{float}. Then the resultant \textit{float} minus the last \textit{double} is promoted to \textit{double}, which is the type for the final result of the expression.

Arrays

An \textit{array} is a group of like-typed variables that are referred to by a common name. Arrays of any type can be created and may have one or more dimensions. A specific element in an array is accessed by its index. Arrays offer a convenient means of grouping related information.

One-Dimensional Arrays

A \textit{one-dimensional array} is, essentially, a list of like-typed variables. To create an array, you first must create an array variable of the desired type. The general form of a one-dimensional array declaration is

\[
\text{type var-name[]};
\]

Here, \textit{type} declares the element type (also called the base type) of the array. The element type determines the data type of each element that comprises the array.
Thus, the element type for the array determines what type of data the array will hold. For example, the following declares an array named `month_days` with the type “array of int”:

```java
int month_days[];
```

Although this declaration establishes the fact that `month_days` is an array variable, no array actually exists. To link `month_days` with an actual, physical array of integers, you must allocate one using `new` and assign it to `month_days`. `new` is a special operator that allocates memory.

You will look more closely at `new` in a later chapter, but you need to use it now to allocate memory for arrays. The general form of `new` as it applies to one-dimensional arrays appears as follows:

```java
array-var = new type [size];
```

Here, `type` specifies the type of data being allocated, `size` specifies the number of elements in the array, and `array-var` is the array variable that is linked to the array. That is, to use `new` to allocate an array, you must specify the type and number of elements to allocate. The elements in the array allocated by `new` will automatically be initialized to zero (for numeric types), `false` (for `boolean`), or `null` (for reference types, which are described in a later chapter). This example allocates a 12-element array of integers and links them to `month_days`:

```java
month_days = new int[12];
```

After this statement executes, `month_days` will refer to an array of 12 integers. Further, all elements in the array will be initialized to zero.

Let’s review: Obtaining an array is a two-step process. First, you must declare a variable of the desired array type. Second, you must allocate the memory that will hold the array, using `new`, and assign it to the array variable. Thus, in Java all arrays are dynamically allocated. If the concept of dynamic allocation is unfamiliar to you, don’t worry. It will be described at length later in this book.

Once you have allocated an array, you can access a specific element in the array by specifying its index within square brackets. All array indexes start at zero. For example, this statement assigns the value 28 to the second element of `month_days`:

```java
month_days[1] = 28;
```

The next line displays the value stored at index 3:

```java
System.out.println(month_days[3]);
```
Putting together all the pieces, here is a program that creates an array of the number of days in each month:

```java
// Demonstrate a one-dimensional array.
class Array {
    public static void main(String args[]) {
        int month_days[];
        month_days = new int[12];
        month_days[0] = 31;
        month_days[1] = 28;
        month_days[2] = 31;
        month_days[3] = 30;
        month_days[4] = 31;
        month_days[5] = 30;
        month_days[6] = 31;
        month_days[7] = 31;
        month_days[8] = 30;
        month_days[9] = 31;
        month_days[10] = 30;
        month_days[11] = 31;
        System.out.println("April has " + month_days[3] + " days.");
    }
}
```

When you run this program, it prints the number of days in April. As mentioned, Java array indexes start with zero, so the number of days in April is `month_days[3]` or 30.

It is possible to combine the declaration of the array variable with the allocation of the array itself, as shown here:

```java
int month_days[] = new int[12];
```

This is the way that you will normally see it done in professionally written Java programs.

Arrays can be initialized when they are declared. The process is much the same as that used to initialize the simple types. An **array initializer** is a list of comma-separated expressions surrounded by curly braces. The commas separate the values of the array elements. The array will automatically be created large enough to hold the number of elements you specify in the array initializer. There is no need to use `new`. For example, to store the number of days in each month, the following code creates an initialized array of integers:
When you run this program, you see the same output as that generated by the previous version.

Java strictly checks to make sure you do not accidentally try to store or reference values outside of the range of the array. The Java run-time system will check that all array indexes are in the correct range. For example, the run-time system will check the value of each index into `month_days` to make sure that it is between 0 and 11 inclusive. If you try to access elements outside the range of the array (negative numbers or numbers greater than the length of the array), you will cause a run-time error.

Here is one more example that uses a one-dimensional array. It finds the average of a set of numbers.

```java
// Average an array of values.
class Average {
    public static void main(String args[]) {
        double nums[] = {10.1, 11.2, 12.3, 13.4, 14.5};
        double result = 0;
        int i;
        for(i=0; i<5; i++)
            result = result + nums[i];
        System.out.println("Average is " + result / 5);
    }
}
```

**Multidimensional Arrays**

In Java, *multidimensional arrays* are implemented as arrays of arrays. To declare a multidimensional array variable, specify each additional index using another set of square brackets. For example, the following declares a two-dimensional array variable called `twoD`:

```java
int twoD[][] = new int[4][5];
```
This allocates a 4 by 5 array and assigns it to twoD. Internally, this matrix is implemented as an array of arrays of int. Conceptually, this array will look like the one shown in Figure 3-1.

Given: int twoD[][] = new int[4][5];

**Figure 3-1**  A conceptual view of a 4 by 5, two-dimensional array

The following program numbers each element in the array from left to right, top to bottom, and then displays these values:
// Demonstrate a two-dimensional array.
class TwoDArray {
    public static void main(String args[]) {
        int twoD[][] = new int[4][5];
        int i, j, k = 0;

        for(i=0; i<4; i++)
            for(j=0; j<5; j++) {
                twoD[i][j] = k;
                k++;
            }

        for(i=0; i<4; i++) {
            for(j=0; j<5; j++)
                System.out.print(twoD[i][j] + " ");
            System.out.println();
        }
    }
}

This program generates the following output:

0 1 2 3 4
5 6 7 8 9
10 11 12 13 14
15 16 17 18 19

When you allocate memory for a multidimensional array, you need only specify the memory for the first (leftmost) dimension. You can allocate the remaining dimensions separately.

For example, this following code allocates memory for the first dimension of twoD when it is declared. It allocates the second dimension separately.

int twoD[][] = new int[4][];
twoD[0] = new int[5];
twoD[1] = new int[5];
twoD[2] = new int[5];
twoD[3] = new int[5];

While there is no advantage to individually allocating the second dimension arrays in this situation, there may be in others. For example, when you allocate dimensions individually, you do not need to allocate the same number of elements for each dimension. As stated earlier, since multidimensional arrays are actually
arrays of arrays, the length of each array is under your control. For example, the
following program creates a two-dimensional array in which the sizes of the second
dimension are unequal:

    // Manually allocate differing size second dimensions.
    class TwoDAgain {
        public static void main(String args[]) {
            int twoD[][] = new int[4][];
            twoD[0] = new int[1];
            twoD[1] = new int[2];
            twoD[2] = new int[3];
            twoD[3] = new int[4];

            int i, j, k = 0;
            for(i=0; i<4; i++)
                for(j=0; j<i+1; j++) {
                    twoD[i][j] = k;
                    k++;
                }

            for(i=0; i<4; i++) {
                for(j=0; j<i+1; j++)
                    System.out.print(twoD[i][j] + " ");
                System.out.println();
            }
        }
    }

This program generates the following output:

    0
    1 2
    3 4 5
    6 7 8 9

The array created by this program looks like this:
The use of uneven (or irregular) multidimensional arrays may not be appropriate for many applications, because it runs contrary to what people expect to find when a multidimensional array is encountered. However, irregular arrays can be used effectively in some situations. For example, if you need a very large two-dimensional array that is sparsely populated (that is, one in which not all of the elements will be used), then an irregular array might be a perfect solution.

It is possible to initialize multidimensional arrays. To do so, simply enclose each dimension’s initializer within its own set of curly braces. The following program creates a matrix where each element contains the product of the row and column indexes. Also notice that you can use expressions as well as literal values inside of array initializers.
When you run this program, you will get the following output:

```
0.0  0.0  0.0  0.0
0.0  1.0  2.0  3.0
0.0  2.0  4.0  6.0
0.0  3.0  6.0  9.0
```

As you can see, each row in the array is initialized as specified in the initialization lists.

Let’s look at one more example that uses a multidimensional array. The following program creates a 3 by 4 by 5, three-dimensional array. It then loads each element with the product of its indexes. Finally, it displays these products.
Alternative Array Declaration Syntax

There is a second form that may be used to declare an array:

```
    type[ ] var-name;
```

Here, the square brackets follow the type specifier, and not the name of the array.
variable. For example, the following two declarations are equivalent:

```java
int a1[] = new int[3];
int[] a2 = new int[3];
```

The following declarations are also equivalent:

```java
char twod1[][] = new char[3][4];
char[][] twod2 = new char[3][4];
```

This alternative declaration form offers convenience when declaring several arrays at the same time. For example,

```java
int[] nums, nums2, nums3; // create three arrays
```

creates three array variables of type `int`. It is the same as writing

```java
int nums[], nums2[], nums3[]; // create three arrays
```

The alternative declaration form is also useful when specifying an array as a return type for a method. Both forms are used in this book.

**A Few Words About Strings**

As you may have noticed, in the preceding discussion of data types and arrays there has been no mention of strings or a string data type. This is not because Java does not support such a type—it does. It is just that Java’s string type, called `String`, is not a primitive type. Nor is it simply an array of characters. Rather, `String` defines an object, and a full description of it requires an understanding of several object-related features. As such, it will be covered later in this book, after objects are described. However, so that you can use simple strings in example programs, the following brief introduction is in order.

The `String` type is used to declare string variables. You can also declare arrays of strings. A quoted string constant can be assigned to a `String` variable. A variable of type `String` can be assigned to another variable of type `String`. You can use an object of type `String` as an argument to `println( )`. For example, consider the following fragment:

```java
String str = "this is a test";
System.out.println(str);
```

Here, `str` is an object of type `String`. It is assigned the string "this is a test". This string is displayed by the `println( )` statement.
As you will see later, **String** objects have many special features and attributes that make them quite powerful and easy to use. However, for the next few chapters, you will be using them only in their simplest form.
CHAPTER
Java provides a rich operator environment. Most of its operators can be divided into the following four groups: arithmetic, bitwise, relational, and logical. Java also defines some additional operators that handle certain special situations. This chapter describes all of Java’s operators except for the type comparison operator instanceof, which is examined in Chapter 13 and the arrow operator (→), which is described in Chapter 15.

Arithmetic Operators

Arithmetic operators are used in mathematical expressions in the same way that they are used in algebra. The following table lists the arithmetic operators:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Addition (also unary plus)</td>
</tr>
<tr>
<td>−</td>
<td>Subtraction (also unary minus)</td>
</tr>
<tr>
<td>*</td>
<td>Multiplication</td>
</tr>
<tr>
<td>/</td>
<td>Division</td>
</tr>
<tr>
<td>%</td>
<td>Modulus</td>
</tr>
<tr>
<td>++</td>
<td>Increment</td>
</tr>
<tr>
<td>+=</td>
<td>Addition assignment</td>
</tr>
<tr>
<td>−=</td>
<td>Subtraction assignment</td>
</tr>
<tr>
<td>*=</td>
<td>Multiplication assignment</td>
</tr>
<tr>
<td>/=</td>
<td>Division assignment</td>
</tr>
<tr>
<td>%=</td>
<td>Modulus assignment</td>
</tr>
<tr>
<td>−−</td>
<td>Decrement</td>
</tr>
</tbody>
</table>

The operands of the arithmetic operators must be of a numeric type. You cannot use them on boolean types, but you can use them on char types, since the char type in Java is, essentially, a subset of int.
The Basic Arithmetic Operators

The basic arithmetic operations—addition, subtraction, multiplication, and division—all behave as you would expect for all numeric types. The unary minus operator negates its single operand. The unary plus operator simply returns the value of its operand. Remember that when the division operator is applied to an integer type, there will be no fractional component attached to the result.

The following simple example program demonstrates the arithmetic operators. It also illustrates the difference between floating-point division and integer division.

```java
// Demonstrate the basic arithmetic operators.
class BasicMath {
    public static void main(String args[]) {
        // arithmetic using integers
        System.out.println("Integer Arithmetic");
        int a = 1 + 1;
        int b = a * 3;
        int c = b / 4;
        int d = c - a;
        int e = -d;
        System.out.println("a = " + a);
        System.out.println("b = " + b);
        System.out.println("c = " + c);
        System.out.println("d = " + d);
        System.out.println("e = " + e);
        
        // arithmetic using doubles
        System.out.println("\nFloating Point Arithmetic");
        double da = 1 + 1;
        double db = da * 3;
        double dc = db / 4;
        double dd = dc - a;
        double de = -dd;
        System.out.println("da = " + da);
        System.out.println("db = " + db);
        System.out.println("dc = " + dc);
        System.out.println("dd = " + dd);
        System.out.println("de = " + de);
    }
}
```

When you run this program, you will see the following output:
The Modulus Operator

The modulus operator, \%, returns the remainder of a division operation. It can be applied to floating-point types as well as integer types. The following example program demonstrates the %:

```java
// Demonstrate the % operator.
class Modulus {
    public static void main(String args[]) {
        int x = 42;
        double y = 42.25;

        System.out.println("x mod 10 = " + x % 10);
        System.out.println("y mod 10 = " + y % 10);
    }
}
```

When you run this program, you will get the following output:

```
x mod 10 = 2
y mod 10 = 2.25
```

Arithmetic Compound Assignment Operators

Java provides special operators that can be used to combine an arithmetic operation with an assignment. As you probably know, statements like the following are quite common in programming:

```
a = a + 4;
```

In Java, you can rewrite this statement as shown here:
This version uses the += compound assignment operator. Both statements perform the same action: they increase the value of a by 4.

Here is another example,

```
a = a % 2;
```

which can be expressed as

```
a %= 2;
```

In this case, the %= obtains the remainder of a /2 and puts that result back into a.

There are compound assignment operators for all of the arithmetic, binary operators. Thus, any statement of the form

```
var = var op expression;
```

can be rewritten as

```
var op= expression;
```

The compound assignment operators provide two benefits. First, they save you a bit of typing, because they are “shorthand” for their equivalent long forms. Second, in some cases they are more efficient than are their equivalent long forms. For these reasons, you will often see the compound assignment operators used in professionally written Java programs.

Here is a sample program that shows several op= assignments in action:

```java
// Demonstrate several assignment operators.
class OpEquals {
    public static void main(String args[]) {
        int a = 1;
        int b = 2;
        int c = 3;

        a += 5;
        b *= 4;
        c += a * b;
        c %= 6;
        System.out.println("a = " + a);
        System.out.println("b = " + b);
        System.out.println("c = " + c);
    }
}
```

The output of this program is shown here:
Increment and Decrement

The ++ and the – – are Java’s increment and decrement operators. They were introduced in Chapter 2. Here they will be discussed in detail. As you will see, they have some special properties that make them quite interesting. Let’s begin by reviewing precisely what the increment and decrement operators do.

The increment operator increases its operand by one. The decrement operator decreases its operand by one. For example, this statement:

\[ x = x + 1; \]

can be rewritten like this by use of the increment operator:

\[ x++; \]

Similarly, this statement:

\[ x = x - 1; \]

is equivalent to

\[ x--; \]

These operators are unique in that they can appear both in postfix form, where they follow the operand as just shown, and prefix form, where they precede the operand. In the foregoing examples, there is no difference between the prefix and postfix forms. However, when the increment and/or decrement operators are part of a larger expression, then a subtle, yet powerful, difference between these two forms appears. In the prefix form, the operand is incremented or decremented before the value is obtained for use in the expression. In postfix form, the previous value is obtained for use in the expression, and then the operand is modified. For example:

\[ x = 42; \]
\[ y = ++x; \]

In this case, \( y \) is set to 43 as you would expect, because the increment occurs before \( x \) is assigned to \( y \). Thus, the line \( y = ++x; \) is the equivalent of these two statements:

\[ x = x + 1; \]
\[ y = x; \]
However, when written like this,

```java
x = 42;
y = x++;
```

the value of `x` is obtained before the increment operator is executed, so the value of `y` is 42. Of course, in both cases `x` is set to 43. Here, the line `y = x++;` is the equivalent of these two statements:

```java
y = x;
x = x + 1;
```

The following program demonstrates the increment operator.

```java
// Demonstrate ++.
class IncDec {
    public static void main(String args[]) {
        int a = 1;
        int b = 2;
        int c;
        int d;
        c = ++b;
        d = a++;
        c++;
        System.out.println("a = " + a);
        System.out.println("b = " + b);
        System.out.println("c = " + c);
        System.out.println("d = " + d);
    }
}
```

The output of this program follows:

```
a = 2
b = 3
c = 4
d = 1
```

**The Bitwise Operators**

Java defines several *bitwise operators* that can be applied to the integer types: `long`, `int`, `short`, `char`, and `byte`. These operators act upon the individual bits of their operands. They are summarized in the following table:
Since the bitwise operators manipulate the bits within an integer: it is important to understand what effects such manipulations may have on a value. Specifically, it is useful to know how Java stores integer values and how it represents negative numbers. So, before continuing, let’s briefly review these two topics.

All of the integer types are represented by binary numbers of varying bit widths. For example, the `byte` value for 42 in binary is 00101010, where each position represents a power of two, starting with $2^0$ at the rightmost bit. The next bit position to the left would be $2^1$, or 2, continuing toward the left with $2^2$, or 4, then 8, 16, 32, and so on. So 42 has 1 bits set at positions 1, 3, and 5 (counting from 0 at the right); thus, 42 is the sum of $2^1 + 2^3 + 2^5$, which is $2 + 8 + 32$.

All of the integer types (except `char`) are signed integers. This means that they can represent negative values as well as positive ones. Java uses an encoding known as two’s complement, which means that negative numbers are represented by inverting (changing 1’s to 0’s and vice versa) all of the bits in a value, then adding 1 to the result. For example, –42 is represented by inverting all of the bits in 42, or 00101010, which yields 11010101, then adding 1, which results in 11010110, or –42. To decode a negative number, first invert all of the bits, then add 1. For example, –42, or 11010110 inverted, yields 00101001, or 41, so when you add 1 you get 42.

The reason Java (and most other computer languages) uses two’s complement is easy to see when you consider the issue of zero crossing. Assuming a `byte` value,
zero is represented by 00000000. In one’s complement, simply inverting all of the bits creates 11111111, which creates negative zero. The trouble is that negative zero is invalid in integer math. This problem is solved by using two’s complement to represent negative values. When using two’s complement, 1 is added to the complement, producing 100000000. This produces a 1 bit too far to the left to fit back into the byte value, resulting in the desired behavior, where –0 is the same as 0, and 11111111 is the encoding for –1. Although we used a byte value in the preceding example, the same basic principle applies to all of Java’s integer types.

Because Java uses two’s complement to store negative numbers—and because all integers are signed values in Java—applying the bitwise operators can easily produce unexpected results. For example, turning on the high-order bit will cause the resulting value to be interpreted as a negative number, whether this is what you intended or not. To avoid unpleasant surprises, just remember that the high-order bit determines the sign of an integer no matter how that high-order bit gets set.

The Bitwise Logical Operators

The bitwise logical operators are &, |, ^, and ~. The following table shows the outcome of each operation. In the discussion that follows, keep in mind that the bitwise operators are applied to each individual bit within each operand.

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>A</th>
<th></th>
<th>B</th>
<th>A &amp; B</th>
<th>A ^ B</th>
<th>~A</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

The Bitwise NOT

Also called the bitwise complement, the unary NOT operator, ~, inverts all of the bits of its operand. For example, the number 42, which has the following bit pattern:

00101010

becomes

11010101

after the NOT operator is applied.

The Bitwise AND
The AND operator, &, produces a 1 bit if both operands are also 1. A zero is produced in all other cases. Here is an example:

\[
\begin{array}{c|c}
00101010 & 42 \\
&00001111 & 15 \\
\hline
00001010 & 10 \\
\end{array}
\]

**The Bitwise OR**

The OR operator, |, combines bits such that if either of the bits in the operands is a 1, then the resultant bit is a 1, as shown here:

\[
\begin{array}{c|c}
00101010 & 42 \\
| 00001111 & 15 \\
\hline
00101111 & 47 \\
\end{array}
\]

**The Bitwise XOR**

The XOR operator, ^, combines bits such that if exactly one operand is 1, then the result is 1. Otherwise, the result is zero. The following example shows the effect of the ^. This example also demonstrates a useful attribute of the XOR operation. Notice how the bit pattern of 42 is inverted wherever the second operand has a 1 bit. Wherever the second operand has a 0 bit, the first operand is unchanged. You will find this property useful when performing some types of bit manipulations.

\[
\begin{array}{c|c}
00101010 & 42 \\
^ 00001111 & 15 \\
\hline
00100101 & 37 \\
\end{array}
\]

**Using the Bitwise Logical Operators**

The following program demonstrates the bitwise logical operators:
In this example, \( a \) and \( b \) have bit patterns that present all four possibilities for two binary digits: 0-0, 0-1, 1-0, and 1-1. You can see how the | and & operate on each bit by the results in \( c \) and \( d \). The values assigned to \( e \) and \( f \) are the same and illustrate how the ^ works. The string array named binary holds the human-readable, binary representation of the numbers 0 through 15. In this example, the array is indexed to show the binary representation of each result. The array is constructed such that the correct string representation of a binary value \( n \) is stored in \( \text{binary}[n] \). The value of ~\( a \) is ANDed with 0x0f (0000 1111 in binary) in order to reduce its value to less than 16, so it can be printed by use of the binary array. Here is the output from this program:

\[
\begin{align*}
a &= 0011 \\
b &= 0110 \\
a|b &= 0111 \\
a\&b &= 0010 \\
a^b &= 0101 \\
\sim a\&b|a\sim b &= 0101 \\
\sim a &= 1100
\end{align*}
\]
The Left Shift

The left shift operator, $<<$, shifts all of the bits in a value to the left a specified number of times. It has this general form:

$$\text{value} \ll \text{num}$$

Here, $\text{num}$ specifies the number of positions to left-shift the value in $\text{value}$. That is, the $\ll$ moves all of the bits in the specified value to the left by the number of bit positions specified by $\text{num}$. For each shift left, the high-order bit is shifted out (and lost), and a zero is brought in on the right. This means that when a left shift is applied to an int operand, bits are lost once they are shifted past bit position 31. If the operand is a long, then bits are lost after bit position 63.

Java’s automatic type promotions produce unexpected results when you are shifting byte and short values. As you know, byte and short values are promoted to int when an expression is evaluated. Furthermore, the result of such an expression is also an int. This means that the outcome of a left shift on a byte or short value will be an int, and the bits shifted left will not be lost until they shift past bit position 31. Furthermore, a negative byte or short value will be sign-extended when it is promoted to int. Thus, the high-order bits will be filled with 1’s. For these reasons, to perform a left shift on a byte or short implies that you must discard the high-order bytes of the int result. For example, if you left-shift a byte value, that value will first be promoted to int and then shifted. This means that you must discard the top three bytes of the result if what you want is the result of a shifted byte value. The easiest way to do this is to simply cast the result back into a byte. The following program demonstrates this concept:

```java
// Left shifting a byte value.
class ByteShift {
    public static void main(String args[]) {
        byte a = 64, b;
        int i;

        i = a << 2;
        b = (byte) (a << 2);

        System.out.println("Original value of a: " + a);
        System.out.println("i and b: " + i + " " + b);
    }
}
```

The output generated by this program is shown here:
Since a is promoted to int for the purposes of evaluation, left-shifting the value 64 (0100 0000) twice results in i containing the value 256 (1 0000 0000). However, the value in b contains 0 because after the shift, the low-order byte is now zero. Its only 1 bit has been shifted out.

Since each left shift has the effect of doubling the original value, programmers frequently use this fact as an efficient alternative to multiplying by 2. But you need to watch out. If you shift a 1 bit into the high-order position (bit 31 or 63), the value will become negative. The following program illustrates this point:

```java
// Left shifting as a quick way to multiply by 2.
class MultByTwo {
    public static void main(String args[]) {
        int i;
        int num = 0xFFFFFFFF;

        for(i=0; i<4; i++) {
            num = num << 1;
            System.out.println(num);
        }
    }
}
```

The program generates the following output:

```
536870908
1073741816
2147483632
-32
```

The starting value was carefully chosen so that after being shifted left 4 bit positions, it would produce –32. As you can see, when a 1 bit is shifted into bit 31, the number is interpreted as negative.

**The Right Shift**

The right shift operator, `>>`, shifts all of the bits in a value to the right a specified number of times. Its general form is shown here:

```
value >> num
```

Here, `num` specifies the number of positions to right-shift the value in `value`. That is, the `>>` moves all of the bits in the specified value to the right the number of bit
positions specified by `num`.

The following code fragment shifts the value 32 to the right by two positions, resulting in `a` being set to 8:

```java
int a = 32;
a = a >> 2;  // a now contains 8
```

When a value has bits that are “shifted off,” those bits are lost. For example, the next code fragment shifts the value 35 to the right two positions, which causes the two low-order bits to be lost, resulting again in `a` being set to 8:

```java
int a = 35;
a = a >> 2;  // a contains 8
```

Looking at the same operation in binary shows more clearly how this happens:

```
00100011  35
>> 2
00001000  8
```

Each time you shift a value to the right, it divides that value by two—and discards any remainder. In some cases, you can take advantage of this for high-performance integer division by 2.

When you are shifting right, the top (leftmost) bits exposed by the right shift are filled in with the previous contents of the top bit. This is called *sign extension* and serves to preserve the sign of negative numbers when you shift them right. For example, –8 >> 1 is –4, which, in binary, is

```
11111000 –8
>> 1
11111100 –4
```

It is interesting to note that if you shift –1 right, the result always remains –1, since sign extension keeps bringing in more ones in the high-order bits.

Sometimes it is not desirable to sign-extend values when you are shifting them to the right. For example, the following program converts a `byte` value to its hexadecimal string representation. Notice that the shifted value is masked by `ANDing` it with `0x0f` to discard any sign-extended bits so that the value can be used as an index into the array of hexadecimal characters.
The Unsigned Right Shift

As you have just seen, the `>>` operator automatically fills the high-order bit with its previous contents each time a shift occurs. This preserves the sign of the value. However, sometimes this is undesirable. For example, if you are shifting something that does not represent a numeric value, you may not want sign extension to take place. This situation is common when you are working with pixel-based values and graphics. In these cases, you will generally want to shift a zero into the high-order bit no matter what its initial value was. This is known as an unsigned shift. To accomplish this, you will use Java’s unsigned, shift-right operator, `>>>`, which always shifts zeros into the high-order bit.

The following code fragment demonstrates the `>>>`. Here, `a` is set to –1, which sets all 32 bits to 1 in binary. This value is then shifted right 24 bits, filling the top 24 bits with zeros, ignoring normal sign extension. This sets `a` to 255.

```java
int a = -1;
a = a >>> 24;
```

Here is the same operation in binary form to further illustrate what is happening:

```
11111111 11111111 11111111 11111111 11111111 11111111 11111111 11111111
-1 in binary as an int

11111111 11111111 11111111 11111111 11111111 11111111 11111111 00000000
>>>24
00000000 00000000 00000000 00000000 11111111 11111111 11111111 11111111
255 in binary as an int
```

The `>>>` operator is often not as useful as you might like, since it is only
meaningful for 32- and 64-bit values. Remember, smaller values are automatically promoted to \texttt{int} in expressions. This means that sign extension occurs and that the shift will take place on a 32-bit rather than on an 8- or 16-bit value. That is, one might expect an unsigned right shift on a \texttt{byte} value to zero-fill beginning at bit 7. But this is not the case, since it is a 32-bit value that is actually being shifted. The following program demonstrates this effect:

```java
// Unsigned shifting a byte value.
class ByteUShift {
    static public void main(String args[]) {
        char hex[] = {
            '0', '1', '2', '3', '4', '5', '6', '7',
            '8', '9', 'a', 'b', 'c', 'd', 'e', 'f'
        };
        byte b = (byte) 0xf1;
        byte c = (byte) (b >> 4);
        byte d = (byte) (b >>> 4);
        byte e = (byte) ((b & 0xff) >> 4);

        System.out.println("b = 0x" + hex[(b >> 4) & 0x0f] + hex[b & 0x0f]);
        System.out.println("b >> 4 = 0x" + hex[(c >> 4) & 0x0f] + hex[c & 0x0f]);
        System.out.println("b >>> 4 = 0x" + hex[(d >> 4) & 0x0f] + hex[d & 0x0f]);
        System.out.println("(b & 0xff) >> 4 = 0x" + hex[(e >> 4) & 0x0f] + hex[e & 0x0f]);
    }
}
```

The following output of this program shows how the >>> operator appears to do nothing when dealing with bytes. The variable \texttt{b} is set to an arbitrary negative \texttt{byte} value for this demonstration. Then \texttt{c} is assigned the \texttt{byte} value of \texttt{b} shifted right by four, which is 0xff because of the expected sign extension. Then \texttt{d} is assigned the \texttt{byte} value of \texttt{b} unsigned shifted right by four, which you might have expected to be 0x0f, but is actually 0xff because of the sign extension that happened when \texttt{b} was promoted to \texttt{int} before the shift. The last expression sets \texttt{e} to the \texttt{byte} value of \texttt{b} masked to 8 bits using the AND operator, then shifted right by four, which produces the expected value of 0x0f. Notice that the unsigned shift right operator was not used for \texttt{d}, since the state of the sign bit after the AND was known.
Bitwise Operator Compound Assignments

All of the binary bitwise operators have a compound form similar to that of the algebraic operators, which combines the assignment with the bitwise operation. For example, the following two statements, which shift the value in `a` right by four bits, are equivalent:

```java
a = a >> 4;
```

```java
a >>= 4;
```

Likewise, the following two statements, which result in `a` being assigned the bitwise expression `a OR b`, are equivalent:

```java
a = a | b;
```

```java
a |= b;
```

The following program creates a few integer variables and then uses compound bitwise operator assignments to manipulate the variables:

```java
class OpBitEquals {
    public static void main(String args[]) {
        int a = 1;
        int b = 2;
        int c = 3;

        a |= 4;
        b >>= 1;
        c <<= 1;
        a ^= c;
        System.out.println("a = "+a);
        System.out.println("b = "+b);
        System.out.println("c = "+c);
    }
}
```

The output of this program is shown here:

```java
a = 3
b = 1
c = 6
```
Relational Operators

The *relational operators* determine the relationship that one operand has to the other. Specifically, they determine equality and ordering. The relational operators are shown here:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>==</td>
<td>Equal to</td>
</tr>
<tr>
<td>!=</td>
<td>Not equal to</td>
</tr>
<tr>
<td>&gt;</td>
<td>Greater than</td>
</tr>
<tr>
<td>&lt;</td>
<td>Less than</td>
</tr>
<tr>
<td>&gt;=</td>
<td>Greater than or equal to</td>
</tr>
<tr>
<td>&lt;=</td>
<td>Less than or equal to</td>
</tr>
</tbody>
</table>

The outcome of these operations is a *boolean* value. The relational operators are most frequently used in the expressions that control the `if` statement and the various loop statements.

Any type in Java, including integers, floating-point numbers, characters, and Booleans can be compared using the equality test, `==`, and the inequality test, `!=`. Notice that in Java equality is denoted with two equal signs, not one. (Remember: a single equal sign is the assignment operator.) Only numeric types can be compared using the ordering operators. That is, only integer, floating-point, and character operands may be compared to see which is greater or less than the other.

As stated, the result produced by a relational operator is a *boolean* value. For example, the following code fragment is perfectly valid:

```java
int a = 4;
int b = 1;
boolean c = a < b;
```

In this case, the result of `a<b` (which is `false`) is stored in `c`.

If you are coming from a C/C++ background, please note the following. In C/C++, these types of statements are very common:

```c
int done;
//...
if(!done)... // Valid in C/C++
if(done)... // but not in Java.
```
In Java, these statements must be written like this:

```java
if (done == 0) ... // This is Java-style.
if (done != 0) ...
```

The reason is that Java does not define true and false in the same way as C/C++. In C/C++, true is any nonzero value and false is zero. In Java, `true` and `false` are nonnumeric values that do not relate to zero or nonzero. Therefore, to test for zero or nonzero, you must explicitly employ one or more of the relational operators.

### Boolean Logical Operators

The Boolean logical operators shown here operate only on `boolean` operands. All of the binary logical operators combine two `boolean` values to form a resultant `boolean` value.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;</td>
<td>Logical AND</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>^</td>
<td>Logical XOR (exclusive OR)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>&amp;&amp;</td>
<td>Short-circuit AND</td>
</tr>
<tr>
<td>!</td>
<td>Logical unary NOT</td>
</tr>
<tr>
<td>&amp;=</td>
<td>AND assignment</td>
</tr>
<tr>
<td></td>
<td>=</td>
</tr>
<tr>
<td>^=</td>
<td>XOR assignment</td>
</tr>
<tr>
<td>==</td>
<td>Equal to</td>
</tr>
<tr>
<td>!=</td>
<td>Not equal to</td>
</tr>
<tr>
<td>?:</td>
<td>Ternary if-then-else</td>
</tr>
</tbody>
</table>

The logical Boolean operators, `&`, `|`, and `^`, operate on `boolean` values in the same way that they operate on the bits of an integer. The logical `!` operator inverts the Boolean state: `!true == false` and `!false == true`. The following table shows the effect of each logical operation:
Here is a program that is almost the same as the BitLogic example shown earlier, but it operates on boolean logical values instead of binary bits:

```java
// Demonstrate the boolean logical operators.
class BoolLogic {
    public static void main(String args[]) {
        boolean a = true;
        boolean b = false;
        boolean c = a | b;
        boolean d = a & b;
        boolean e = a ^ b;
        boolean f = (!a & b) | (a & !b);
        boolean g = !a;
        System.out.println("a = " + a);
        System.out.println("b = " + b);
        System.out.println("a|b = " + c);
        System.out.println("a&b = " + d);
        System.out.println("a^b = " + e);
        System.out.println("!a|b|a&!b = " + f);
        System.out.println("!a = " + g);
    }
}
```

After running this program, you will see that the same logical rules apply to boolean values as they did to bits. As you can see from the following output, the string representation of a Java boolean value is one of the literal values true or false:

```
a = true
b = false
a|b = true
a&b = false
a^b = true
!a|b|a&!b = true
!a = false
```
Short-Circuit Logical Operators

Java provides two interesting Boolean operators not found in some other computer languages. These are secondary versions of the Boolean AND and OR operators, and are commonly known as short-circuit logical operators. As you can see from the preceding table, the OR operator results in true when \( A \) is true, no matter what \( B \) is. Similarly, the AND operator results in false when \( A \) is false, no matter what \( B \) is. If you use the || and && forms, rather than the | and & forms of these operators, Java will not bother to evaluate the right-hand operand when the outcome of the expression can be determined by the left operand alone. This is very useful when the right-hand operand depends on the value of the left one in order to function properly. For example, the following code fragment shows how you can take advantage of short-circuit logical evaluation to be sure that a division operation will be valid before evaluating it:

```java
if (denom != 0 && num / denom > 10)
```

Since the short-circuit form of AND (&&) is used, there is no risk of causing a run-time exception when \( \text{denom} \) is zero. If this line of code were written using the single & version of AND, both sides would be evaluated, causing a run-time exception when \( \text{denom} \) is zero.

It is standard practice to use the short-circuit forms of AND and OR in cases involving Boolean logic, leaving the single-character versions exclusively for bitwise operations. However, there are exceptions to this rule. For example, consider the following statement:

```java
if(c==1 & e++ < 100) d = 100;
```

Here, using a single & ensures that the increment operation will be applied to \( e \) whether \( c \) is equal to 1 or not.

**NOTE** The formal specification for Java refers to the short-circuit operators as the conditional-and and the conditional-or.

The Assignment Operator

You have been using the assignment operator since Chapter 2. Now it is time to take a formal look at it. The assignment operator is the single equal sign, =. The assignment operator works in Java much as it does in any other computer language. It has this general form:

```
var = expression;
```
Here, the type of var must be compatible with the type of expression.

The assignment operator does have one interesting attribute that you may not be familiar with: it allows you to create a chain of assignments. For example, consider this fragment:

```java
int x, y, z;

x = y = z = 100; // set x, y, and z to 100
```

This fragment sets the variables x, y, and z to 100 using a single statement. This works because the = is an operator that yields the value of the right-hand expression. Thus, the value of z = 100 is 100, which is then assigned to y, which in turn is assigned to x. Using a “chain of assignment” is an easy way to set a group of variables to a common value.

### The ? Operator

Java includes a special ternary (three-way) operator that can replace certain types of if-then-else statements. This operator is the ?. It can seem somewhat confusing at first, but the ? can be used very effectively once mastered. The ? has this general form:

```java
expression1 ? expression2 : expression3
```

Here, expression1 can be any expression that evaluates to a boolean value. If expression1 is true, then expression2 is evaluated; otherwise, expression3 is evaluated. The result of the ? operation is that of the expression evaluated. Both expression2 and expression3 are required to return the same (or compatible) type, which can’t be void.

Here is an example of the way that the ? is employed:

```java
ratio = denom == 0 ? 0 : num / denom;
```

When Java evaluates this assignment expression, it first looks at the expression to the left of the question mark. If denom equals zero, then the expression between the question mark and the colon is evaluated and used as the value of the entire ? expression. If denom does not equal zero, then the expression after the colon is evaluated and used for the value of the entire ? expression. The result produced by the ? operator is then assigned to ratio.

Here is a program that demonstrates the ? operator. It uses it to obtain the absolute value of a variable.
// Demonstrate ?.
class Ternary {
    public static void main(String args[]) {
        int i, k;

        i = 10;
        k = i < 0 ? -i : i; // get absolute value of i
        System.out.print("Absolute value of ");
        System.out.println(i + " is " + k);

        i = -10;
        k = i < 0 ? -i : i; // get absolute value of i
        System.out.print("Absolute value of ");
        System.out.println(i + " is " + k);
    }
}

The output generated by the program is shown here:

    Absolute value of 10 is 10
    Absolute value of -10 is 10

**Operator Precedence**

Table 4-1 shows the order of precedence for Java operators, from highest to lowest. Operators in the same row are equal in precedence. In binary operations, the order of evaluation is left to right (except for assignment, which evaluates right to left). Although they are technically separators, the [], ( ), and . can also act like operators. In that capacity, they would have the highest precedence. Also, notice the arrow operator (->). It is used in lambda expressions.
# Using Parentheses

*Parentheses* raise the precedence of the operations that are inside them. This is often necessary to obtain the result you desire. For example, consider the following expression:

\[ a \gg b + 3 \]

This expression first adds 3 to \( b \) and then shifts \( a \) right by that result. That is, this expression can be rewritten using redundant parentheses like this:

\[ a \gg (b + 3) \]

However, if you want to first shift \( a \) right by \( b \) positions and then add 3 to that result, you will need to parenthesize the expression like this:

\[ a \gg (b + 3) \]
In addition to altering the normal precedence of an operator, parentheses can sometimes be used to help clarify the meaning of an expression. For anyone reading your code, a complicated expression can be difficult to understand. Adding redundant but clarifying parentheses to complex expressions can help prevent confusion later. For example, which of the following expressions is easier to read?

\[
\begin{align*}
(a \gg b) + 3 \\
\text{a } | \ 4 + c \gg b \ & \ 7 \\
(a \ | \ ((4 + c) \gg b) \ & \ 7)
\end{align*}
\]

One other point: parentheses (redundant or not) do not degrade the performance of your program. Therefore, adding parentheses to reduce ambiguity does not negatively affect your program.
CHAPTER
A programming language uses control statements to cause the flow of execution to advance and branch based on changes to the state of a program. Java’s program control statements can be put into the following categories: selection, iteration, and jump. Selection statements allow your program to choose different paths of execution based upon the outcome of an expression or the state of a variable. Iteration statements enable program execution to repeat one or more statements (that is, iteration statements form loops). Jump statements allow your program to execute in a nonlinear fashion. All of Java’s control statements are examined here.

### Java’s Selection Statements

Java supports two selection statements: `if` and `switch`. These statements allow you to control the flow of your program’s execution based upon conditions known only during run time. You will be pleasantly surprised by the power and flexibility contained in these two statements.

#### if

The `if` statement was introduced in Chapter 2. It is examined in detail here. The `if` statement is Java’s conditional branch statement. It can be used to route program execution through two different paths. Here is the general form of the `if` statement:

```java
if (condition) statement1;
else statement2;
```

Here, each `statement` may be a single statement or a compound statement enclosed in curly braces (that is, a block). The `condition` is any expression that returns a `boolean` value. The `else` clause is optional.

The `if` works like this: If the `condition` is true, then `statement1` is executed. Otherwise, `statement2` (if it exists) is executed. In no case will both statements be executed. For example, consider the following:
Here, if \( a \) is less than \( b \), then \( a \) is set to zero. Otherwise, \( b \) is set to zero. In no case are they both set to zero.

Most often, the expression used to control the \textbf{if} will involve the relational operators. However, this is not technically necessary. It is possible to control the \textbf{if} using a single \textbf{boolean} variable, as shown in this code fragment:

```java
boolean dataAvailable;
//...
if (dataAvailable)
    ProcessData();
else
    waitForMoreData();
```

Remember, only one statement can appear directly after the \textbf{if} or the \textbf{else}. If you want to include more statements, you’ll need to create a block, as in this fragment:

```java
int bytesAvailable;
// ...
if (bytesAvailable > 0) {
    ProcessData();
    bytesAvailable -= n;
} else
    waitForMoreData();
```

Here, both statements within the \textbf{if} block will execute if \textbf{bytesAvailable} is greater than zero.

Some programmers find it convenient to include the curly braces when using the \textbf{if}, even when there is only one statement in each clause. This makes it easy to add another statement at a later date, and you don’t have to worry about forgetting the braces. In fact, forgetting to define a block when one is needed is a common cause of errors. For example, consider the following code fragment:
int bytesAvailable;
// ...
if (bytesAvailable > 0) {
    ProcessData();
    bytesAvailable -= n;
} else {
    waitForMoreData();
    bytesAvailable = n;
}

It seems clear that the statement `bytesAvailable = n;` was intended to be executed inside the `else` clause, because of the indentation level. However, as you recall, whitespace is insignificant to Java, and there is no way for the compiler to know what was intended. This code will compile without complaint, but it will behave incorrectly when run. The preceding example is fixed in the code that follows:

```java
int bytesAvailable;
// ...
if (bytesAvailable > 0) {
    ProcessData();
    bytesAvailable -= n;
} else {
    waitForMoreData();
    bytesAvailable = n;
}
```

### Nested ifs

A *nested if* is an if statement that is the target of another if or else. Nested ifs are very common in programming. When you nest ifs, the main thing to remember is that an else statement always refers to the nearest if statement that is within the same block as the else and that is not already associated with an else. Here is an example:

```java
if(i == 10) {
    if(j < 20) a = b;
    if(k > 100) c = d; // this if is
    else a = c; // associated with this else
} else a = d; // this else refers to if(i == 10)
```

As the comments indicate, the final else is not associated with `if(j<20)` because it is not in the same block (even though it is the nearest if without an else). Rather, the final else is associated with `if(i==10)`. The inner else refers to `if(k>100)` because it is the closest if within the same block.
The if-else-if Ladder
A common programming construct that is based upon a sequence of nested if statements is the if-else-if ladder. It looks like this:

```java
if(condition)
    statement;
else if(condition)
    statement;
else if(condition)
    statement;
.
.
else
    statement;
```

The if statements are executed from the top down. As soon as one of the conditions controlling the if is true, the statement associated with that if is executed, and the rest of the ladder is bypassed. If none of the conditions is true, then the final else statement will be executed. The final else acts as a default condition; that is, if all other conditional tests fail, then the last else statement is performed. If there is no final else and all other conditions are false, then no action will take place.

Here is a program that uses an if-else-if ladder to determine which season a particular month is in.
Here is the output produced by the program:

    April is in the Spring.

You might want to experiment with this program before moving on. As you will find, no matter what value you give `month`, one and only one assignment statement within the ladder will be executed.

**switch**

The `switch` statement is Java’s multiway branch statement. It provides an easy way to dispatch execution to different parts of your code based on the value of an expression. As such, it often provides a better alternative than a large series of `if-else-if` statements. Here is the general form of a `switch` statement:
switch (expression) {
    case value1:
        // statement sequence
        break;
    case value2:
        // statement sequence
        break;
    .
    .
    .
    case valueN:
        // statement sequence
        break;
    default:
        // default statement sequence
}

For versions of Java prior to JDK 7, expression must resolve to type byte, short, int, char, or an enumeration. (Enumerations are described in Chapter 12.) Beginning with JDK 7, expression can also be of type String. Each value specified in the case statements must be a unique constant expression (such as a literal value). Duplicate case values are not allowed. The type of each value must be compatible with the type of expression.

The switch statement works like this: The value of the expression is compared with each of the values in the case statements. If a match is found, the code sequence following that case statement is executed. If none of the constants matches the value of the expression, then the default statement is executed. However, the default statement is optional. If no case matches and no default is present, then no further action is taken.

The break statement is used inside the switch to terminate a statement sequence. When a break statement is encountered, execution branches to the first line of code that follows the entire switch statement. This has the effect of “jumping out” of the switch.

Here is a simple example that uses a switch statement:

```java
switch (expression) {
    case value1:
        // statement sequence
        break;
    case value2:
        // statement sequence
        break;
    .
    .
    .
    case valueN:
        // statement sequence
        break;
    default:
        // default statement sequence
}
```
The output produced by this program is shown here:

```
i is zero.
i is one.
i is two.
i is three.
i is greater than 3.
i is greater than 3.
```

As you can see, each time through the loop, the statements associated with the `case` constant that matches `i` are executed. All others are bypassed. After `i` is greater than 3, no `case` statements match, so the `default` statement is executed.

The `break` statement is optional. If you omit the `break`, execution will continue on into the next `case`. It is sometimes desirable to have multiple `cases` without `break` statements between them. For example, consider the following program:
// In a switch, break statements are optional.
class MissingBreak {
    public static void main(String args[]) {
        for(int i=0; i<12; i++)
            switch(i) {
                case 0:
                    case 1:
                    case 2:
                    case 3:
                    case 4:
                        System.out.println("i is less than 5");
                        break;
                    case 5:
                    case 6:
                    case 7:
                    case 8:
                    case 9:
                        System.out.println("i is less than 10");
                        break;
                    default:
                        System.out.println("i is 10 or more");
            }
    }
}

This program generates the following output:

i is less than 5
i is less than 5
i is less than 5
i is less than 5
i is less than 5
i is less than 10
i is less than 10
i is less than 10
i is less than 10
i is less than 10
i is less than 10
i is 10 or more
i is 10 or more

As you can see, execution falls through each case until a break statement (or the end of the switch) is reached.

While the preceding example is, of course, contrived for the sake of illustration, omitting the break statement has many practical applications in real programs. To
sample its more realistic usage, consider the following rewrite of the season example shown earlier. This version uses a switch to provide a more efficient implementation.

```java
// An improved version of the season program.
class Switch {
    public static void main(String args[]) {
        int month = 4;
        String season;

        switch (month) {
            case 12:
            case 1:
            case 2:
                season = "Winter";
                break;
            case 3:
            case 4:
            case 5:
                season = "Spring";
                break;
            case 6:
            case 7:
            case 8:
                season = "Summer";
                break;
            case 9:
            case 10:
            case 11:
                season = "Autumn";
                break;
            default:
                season = "Bogus Month";
        }
        System.out.println("April is in the " + season + ".");
    }
}
```

As mentioned, beginning with JDK 7, you can use a string to control a switch statement. For example,
As you would expect, the output from the program is

two

The string contained in `str` (which is "two" in this program) is tested against the `case` constants. When a match is found (as it is in the second `case`), the code sequence associated with that sequence is executed.

Being able to use strings in a `switch` statement streamlines many situations. For example, using a string-based `switch` is an improvement over using the equivalent sequence of `if/else` statements. However, switching on strings can be more expensive than switching on integers. Therefore, it is best to switch on strings only in cases in which the controlling data is already in string form. In other words, don’t use strings in a `switch` unnecessarily.

**Nested switch Statements**

You can use a `switch` as part of the statement sequence of an outer `switch`. This is called a `nested switch`. Since a `switch` statement defines its own block, no conflicts arise between the `case` constants in the inner `switch` and those in the outer `switch`. For example, the following fragment is perfectly valid:
switch(count) {
    case 1:
        switch(target) { // nested switch
            case 0:
                System.out.println("target is zero");
                break;
            case 1: // no conflicts with outer switch
                System.out.println("target is one");
                break;
        }
        break;
    case 2: // ...
}

Here, the case 1: statement in the inner switch does not conflict with the case 1: statement in the outer switch. The count variable is compared only with the list of cases at the outer level. If count is 1, then target is compared with the inner list cases.

In summary, there are three important features of the switch statement to note:

- The switch differs from the if in that switch can only test for equality, whereas if can evaluate any type of Boolean expression. That is, the switch looks only for a match between the value of the expression and one of its case constants.
- No two case constants in the same switch can have identical values. Of course, a switch statement and an enclosing outer switch can have case constants in common.
- A switch statement is usually more efficient than a set of nested ifs.

The last point is particularly interesting because it gives insight into how the Java compiler works. When it compiles a switch statement, the Java compiler will inspect each of the case constants and create a “jump table” that it will use for selecting the path of execution depending on the value of the expression. Therefore, if you need to select among a large group of values, a switch statement will run much faster than the equivalent logic coded using a sequence of if-elses. The compiler can do this because it knows that the case constants are all the same type and simply must be compared for equality with the switch expression. The compiler has no such knowledge of a long list of if expressions.

**Iteration Statements**

Java’s iteration statements are for, while, and do-while. These statements create
what we commonly call *loops*. As you probably know, a loop repeatedly executes the same set of instructions until a termination condition is met. As you will see, Java has a loop to fit any programming need.

**while**

The **while** loop is Java’s most fundamental loop statement. It repeats a statement or block while its controlling expression is true. Here is its general form:

```java
while(condition) {
   // body of loop
}
```

The *condition* can be any Boolean expression. The body of the loop will be executed as long as the conditional expression is true. When *condition* becomes false, control passes to the next line of code immediately following the loop. The curly braces are unnecessary if only a single statement is being repeated.

Here is a **while** loop that counts down from 10, printing exactly ten lines of "tick":

```java
// Demonstrate the while loop.
class While {
   public static void main(String args[]) {
      int n = 10;

      while(n > 0) {
         System.out.println("tick " + n);
         n--;
      }
   }
}
```

When you run this program, it will “tick” ten times:
Since the **while** loop evaluates its conditional expression at the top of the loop, the body of the loop will not execute even once if the condition is false to begin with. For example, in the following fragment, the call to `println()` is never executed:

```java
int a = 10, b = 20;

while(a > b)
    System.out.println("This will not be displayed");
```

The body of the **while** (or any other of Java’s loops) can be empty. This is because a null statement (one that consists only of a semicolon) is syntactically valid in Java. For example, consider the following program:

```java
// The target of a loop can be empty.
class NoBody {
    public static void main(String args[]) {
        int i, j;

        i = 100;
        j = 200;

        // find midpoint between i and j
        while(++i < --j); // no body in this loop

        System.out.println("Midpoint is " + i);
    }
}
```

This program finds the midpoint between `i` and `j`. It generates the following output:

```
Midpoint is 150
```

Here is how this **while** loop works. The value of `i` is incremented, and the value of `j` is decremented. These values are then compared with one another. If the new value
of \(i\) is still less than the new value of \(j\), then the loop repeats. If \(i\) is equal to or greater than \(j\), the loop stops. Upon exit from the loop, \(i\) will hold a value that is midway between the original values of \(i\) and \(j\). (Of course, this procedure only works when \(i\) is less than \(j\) to begin with.) As you can see, there is no need for a loop body; all of the action occurs within the conditional expression, itself. In professionally written Java code, short loops are frequently coded without bodies when the controlling expression can handle all of the details itself.

**do-while**

As you just saw, if the conditional expression controlling a *while* loop is initially false, then the body of the loop will not be executed at all. However, sometimes it is desirable to execute the body of a loop at least once, even if the conditional expression is false to begin with. In other words, there are times when you would like to test the termination expression at the end of the loop rather than at the beginning. Fortunately, Java supplies a loop that does just that: the *do-while*. The *do-while* loop always executes its body at least once, because its conditional expression is at the bottom of the loop. Its general form is

```java
do {
  // body of loop
} while (condition);
```

Each iteration of the *do-while* loop first executes the body of the loop and then evaluates the conditional expression. If this expression is true, the loop will repeat. Otherwise, the loop terminates. As with all of Java’s loops, *condition* must be a Boolean expression.

Here is a reworked version of the “tick” program that demonstrates the *do-while* loop. It generates the same output as before.

```java
// Demonstrate the do-while loop.
class DoWhile {
  public static void main(String args[]) {
    int n = 10;

    do {
      System.out.println("tick " + n);
      n--;  
    } while(n > 0);
  }
}
```
The loop in the preceding program, while technically correct, can be written more efficiently as follows:

```java
do {
    System.out.println("tick " + n);
} while(--n > 0);
```

In this example, the expression `(--n > 0)` combines the decrement of `n` and the test for zero into one expression. Here is how it works. First, the `--n` statement executes, decrementing `n` and returning the new value of `n`. This value is then compared with zero. If it is greater than zero, the loop continues; otherwise, it terminates.

The **do-while** loop is especially useful when you process a menu selection, because you will usually want the body of a menu loop to execute at least once. Consider the following program, which implements a very simple help system for Java’s selection and iteration statements:
// Using a do-while to process a menu selection
class Menu {
    public static void main(String args[])
        throws java.io.IOException {
            char choice;

            do {
                System.out.println("Help on: ");
                System.out.println("  1. if");
                System.out.println("  2. switch");
                System.out.println("  3. while");
                System.out.println("  4. do-while");
                System.out.println("  5. for\n");
                System.out.println("Choose one:");
                choice = (char) System.in.read();
            } while (choice < '1' || choice > '5');

            System.out.println("\n");

            switch(choice) {
                case '1':
                    System.out.println("The if:\n");
                    System.out.println("if(condition) statement; ");
                    System.out.println("else statement; ");
                    break;
                case '2':
                    System.out.println("The switch:\n");
                    System.out.println("switch(expression) { ");
                    System.out.println("    case constant: ");
                    System.out.println("        statement sequence ");
                    System.out.println("    break; ");
                    System.out.println("  //... ");
                    System.out.println("} ");
                    break;
                case '3':
                    System.out.println("The while:\n");
                    System.out.println("while(condition) statement; ");
                    break;
                case '4':
                    System.out.println("The do-while:\n");
                    System.out.println("do ");
                    System.out.println("    statement; ");
                    System.out.println("} while (condition); ");
                    break;
                case '5':
                    System.out.println("The for:\n");
                    System.out.println("for(init; condition; iteration) ");
                    System.out.println(" statement; ");
                    break;
            }
        }
    }
}
Here is a sample run produced by this program:

```
Help on:
  1. if
  2. switch
  3. while
  4. do-while
  5. for
Choose one:
  4
The do-while:
  do {
    statement;
  } while (condition);
```

In the program, the **do-while** loop is used to verify that the user has entered a valid choice. If not, then the user is reprompted. Since the menu must be displayed at least once, the **do-while** is the perfect loop to accomplish this.

A few other points about this example: Notice that characters are read from the keyboard by calling `System.in.read()`). This is one of Java’s console input functions. Although Java’s console I/O methods won’t be discussed in detail until Chapter 13, `System.in.read()` is used here to obtain the user’s choice. It reads characters from standard input (returned as integers, which is why the return value was cast to `char`). By default, standard input is line buffered, so you must press enter before any characters that you type will be sent to your program.

Java’s console input can be a bit awkward to work with. Further, most real-world Java programs will use a graphical user interface (GUI). For these reasons, not much use of console input has been made in this book. However, it is useful in this context. One other point to consider: Because `System.in.read()` is being used, the program must specify the `throws java.io.IOException` clause. This line is necessary to handle input errors. It is part of Java’s exception handling features, which are discussed in Chapter 10.

**for**

You were introduced to a simple form of the **for** loop in Chapter 2. As you will see, it is a powerful and versatile construct.

There are two forms of the **for** loop. The first is the traditional form that has been in use since the original version of Java. The second is the newer “for-each” form, added by JDK 5. Both types of **for** loops are discussed here, beginning with the traditional form.
Here is the general form of the traditional `for` statement:

```java
for(initialization; condition; iteration) {
    // body
}
```

If only one statement is being repeated, there is no need for the curly braces.

The `for` loop operates as follows. When the loop first starts, the *initialization* portion of the loop is executed. Generally, this is an expression that sets the value of the *loop control variable*, which acts as a counter that controls the loop. It is important to understand that the initialization expression is executed only once. Next, *condition* is evaluated. This must be a Boolean expression. It usually tests the loop control variable against a target value. If this expression is true, then the body of the loop is executed. If it is false, the loop terminates. Next, the *iteration* portion of the loop is executed. This is usually an expression that increments or decrements the loop control variable. The loop then iterates, first evaluating the conditional expression, then executing the body of the loop, and then executing the iteration expression with each pass. This process repeats until the controlling expression is false.

Here is a version of the “tick” program that uses a `for` loop:

```java
// Demonstrate the for loop.
class ForTick {
    public static void main(String args[]) {
        int n;
        for(n=10; n>0; n--)
            System.out.println("tick "+n);
    }
}
```

**Declaring Loop Control Variables Inside the for Loop**

Often the variable that controls a `for` loop is needed only for the purposes of the loop and is not used elsewhere. When this is the case, it is possible to declare the variable inside the initialization portion of the `for`. For example, here is the preceding program recoded so that the loop control variable `n` is declared as an `int` inside the `for`:
// Declare a loop control variable inside the for.
class ForTick {
    public static void main(String args[]) {
        // here, n is declared inside of the for loop
        for(int n=10; n>0; n--)
            System.out.println("tick " + n);
    }
}

When you declare a variable inside a for loop, there is one important point to remember: the scope of that variable ends when the for statement does. (That is, the scope of the variable is limited to the for loop.) Outside the for loop, the variable will cease to exist. If you need to use the loop control variable elsewhere in your program, you will not be able to declare it inside the for loop.

When the loop control variable will not be needed elsewhere, most Java programmers declare it inside the for. For example, here is a simple program that tests for prime numbers. Notice that the loop control variable, i, is declared inside the for since it is not needed elsewhere.

// Test for primes.
class FindPrime {
    public static void main(String args[]) {
        int num;
        boolean isPrime;

        num = 14;

        if(num < 2) isPrime = false;
        else isPrime = true;

        for(int i=2; i <= num/i; i++) {
            if((num % i == 0) {
                isPrime = false;
                break;
            }
        }

        if(isPrime) System.out.println("Prime");
        else System.out.println("Not Prime");
    }
}
Using the Comma

There will be times when you will want to include more than one statement in the initialization and iteration portions of the for loop. For example, consider the loop in the following program:

```java
class Sample {
    public static void main(String args[]) {
        int a, b;

        b = 4;
        for(a=1; a<b; a++) {
            System.out.println("a = " + a);
            System.out.println("b = " + b);
            b--;  
        }
    }
}
```

As you can see, the loop is controlled by the interaction of two variables. Since the loop is governed by two variables, it would be useful if both could be included in the for statement, itself, instead of b being handled manually. Fortunately, Java provides a way to accomplish this. To allow two or more variables to control a for loop, Java permits you to include multiple statements in both the initialization and iteration portions of the for. Each statement is separated from the next by a comma.

Using the comma, the preceding for loop can be more efficiently coded, as shown here:

```java
// Using the comma.
class Comma {
    public static void main(String args[]) {
        int a, b;

        for(a=1, b=4; a<b; a++, b--) {
            System.out.println("a = " + a);
            System.out.println("b = " + b);
        }
    }
}
```

In this example, the initialization portion sets the values of both a and b. The two comma-separated statements in the iteration portion are executed each time the loop repeats. The program generates the following output:
Some for Loop Variations
The for loop supports a number of variations that increase its power and applicability. The reason it is so flexible is that its three parts—the initialization, the conditional test, and the iteration—do not need to be used for only those purposes. In fact, the three sections of the for can be used for any purpose you desire. Let’s look at some examples.

One of the most common variations involves the conditional expression. Specifically, this expression does not need to test the loop control variable against some target value. In fact, the condition controlling the for can be any Boolean expression. For example, consider the following fragment:

```java
boolean done = false;

for(int i=1; !done; i++) {
    // ...
    if(interrupted()) done = true;
}
```

In this example, the for loop continues to run until the boolean variable done is set to true. It does not test the value of i.

Here is another interesting for loop variation. Either the initialization or the iteration expression or both may be absent, as in this next program:

```java
// Parts of the for loop can be empty.
class ForVar {
    public static void main(String args[]) {
        int i;
        boolean done = false;

        i = 0;
        for( ; !done; ) {
            System.out.println("i is "+i);
            if(i == 10) done = true;
            i++;
        }
    }
}
```
Here, the initialization and iteration expressions have been moved out of the for. Thus, parts of the for are empty. While this is of no value in this simple example—indeed, it would be considered quite poor style—there can be times when this type of approach makes sense. For example, if the initial condition is set through a complex expression elsewhere in the program or if the loop control variable changes in a nonsequential manner determined by actions that occur within the body of the loop, it may be appropriate to leave these parts of the for empty.

Here is one more for loop variation. You can intentionally create an infinite loop (a loop that never terminates) if you leave all three parts of the for empty. For example:

```java
for( ; ; ) {
    // ...
}
```

This loop will run forever because there is no condition under which it will terminate. Although there are some programs, such as operating system command processors, that require an infinite loop, most “infinite loops” are really just loops with special termination requirements. As you will soon see, there is a way to terminate a loop—even an infinite loop like the one shown—that does not make use of the normal loop conditional expression.

The For-Each Version of the for Loop

A second form of for implements a “for-each” style loop. As you may know, contemporary language theory has embraced the for-each concept, and it has become a standard feature that programmers have come to expect. A for-each style loop is designed to cycle through a collection of objects, such as an array, in strictly sequential fashion, from start to finish. In Java, the for-each style of for is also referred to as the enhanced for loop.

The general form of the for-each version of the for is shown here:

```java
for(type itr-var : collection) statement-block
```

Here, type specifies the type and itr-var specifies the name of an iteration variable that will receive the elements from a collection, one at a time, from beginning to end. The collection being cycled through is specified by collection. There are various types of collections that can be used with the for, but the only type used in this chapter is the array. (Other types of collections that can be used with the for, such as those defined by the Collections Framework, are discussed later in this book.) With each iteration of the loop, the next element in the collection is retrieved and stored in
itr-var. The loop repeats until all elements in the collection have been obtained.

Because the iteration variable receives values from the collection, type must be the same as (or compatible with) the elements stored in the collection. Thus, when iterating over arrays, type must be compatible with the element type of the array.

To understand the motivation behind a for-each style loop, consider the type of for loop that it is designed to replace. The following fragment uses a traditional for loop to compute the sum of the values in an array:

```java
int nums[] = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 };
int sum = 0;

for(int i=0; i < 10; i++) sum += nums[i];
```

To compute the sum, each element in nums is read, in order, from start to finish. Thus, the entire array is read in strictly sequential order. This is accomplished by manually indexing the nums array by i, the loop control variable.

The for-each style for automates the preceding loop. Specifically, it eliminates the need to establish a loop counter, specify a starting and ending value, and manually index the array. Instead, it automatically cycles through the entire array, obtaining one element at a time, in sequence, from beginning to end. For example, here is the preceding fragment rewritten using a for-each version of the for:

```java
int nums[] = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 };
int sum = 0;

for(int x: nums) sum += x;
```

With each pass through the loop, x is automatically given a value equal to the next element in nums. Thus, on the first iteration, x contains 1; on the second iteration, x contains 2; and so on. Not only is the syntax streamlined, but it also prevents boundary errors.

Here is an entire program that demonstrates the for-each version of the for just described:
// Use a for-each style for loop.
class ForEach {
    public static void main(String args[]) {
        int nums[] = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 };
        int sum = 0;

        // use for-each style for to display and sum the values
        for(int x : nums) {
            System.out.println("Value is: ", + x);
            sum += x;
        }

        System.out.println("Summation: ", + sum);
    }
}

The output from the program is shown here:

Value is: 1
Value is: 2
Value is: 3
Value is: 4
Value is: 5
Value is: 6
Value is: 7
Value is: 8
Value is: 9
Value is: 10
Summation: 55

As this output shows, the for-each style for automatically cycles through an array in sequence from the lowest index to the highest.

Although the for-each for loop iterates until all elements in an array have been examined, it is possible to terminate the loop early by using a break statement. For example, this program sums only the first five elements of nums:
// Use break with a for-each style for.
class ForEach2 {
    public static void main(String args[]) {
        int sum = 0;
        int nums[] = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 };

        // use for to display and sum the values
        for(int x : nums) {
            System.out.println("Value is: " + x);
            sum += x;
            if(x == 5) break; // stop the loop when 5 is obtained
        }
        System.out.println("Summation of first 5 elements: " + sum);
    }
}

This is the output produced:

Value is: 1
Value is: 2
Value is: 3
Value is: 4
Value is: 5
Summation of first 5 elements: 15

As is evident, the for loop stops after the fifth element has been obtained. The break statement can also be used with Java’s other loops, and it is discussed in detail later in this chapter.

There is one important point to understand about the for-each style loop. Its iteration variable is “read-only” as it relates to the underlying array. An assignment to the iteration variable has no effect on the underlying array. In other words, you can’t change the contents of the array by assigning the iteration variable a new value. For example, consider this program:
The first for loop increases the value of the iteration variable by a factor of 10. However, this assignment has no effect on the underlying array nums, as the second for loop illustrates. The output, shown here, proves this point:

```
1 2 3 4 5 6 7 8 9 10
1 2 3 4 5 6 7 8 9 10
```

**Iterating Over Multidimensional Arrays**

The enhanced version of the for also works on multidimensional arrays. Remember, however, that in Java, multidimensional arrays consist of arrays of arrays. (For example, a two-dimensional array is an array of one-dimensional arrays.) This is important when iterating over a multidimensional array, because each iteration obtains the next array, not an individual element. Furthermore, the iteration variable in the for loop must be compatible with the type of array being obtained. For example, in the case of a two-dimensional array, the iteration variable must be a reference to a one-dimensional array. In general, when using the for-each for to iterate over an array of N dimensions, the objects obtained will be arrays of N–1 dimensions. To understand the implications of this, consider the following program. It uses nested for loops to obtain the elements of a two-dimensional array in row-order, from first to last.
// Use for-each style for on a two-dimensional array.
class ForEach3 {
    public static void main(String args[]) {
        int sum = 0;
        int nums[][] = new int[3][5];

        // give nums some values
        for(int i = 0; i < 3; i++)
            for(int j = 0; j < 5; j++)
                nums[i][j] = (i+1)*(j+1);

        // use for-each for to display and sum the values
        for(int x[] : nums) {
            for(int y : x) {
                System.out.println("Value is: "+y);
                sum += y;
            }
        }
        System.out.println("Summation: "+sum);
    }
}

The output from this program is shown here:

Value is: 1
Value is: 2
Value is: 3
Value is: 4
Value is: 5
Value is: 2
Value is: 4
Value is: 6
Value is: 8
Value is: 10
Value is: 3
Value is: 6
Value is: 9
Value is: 12
Value is: 15
Summation: 90

In the program, pay special attention to this line:

for(int x[]: nums) {

Notice how \( x \) is declared. It is a reference to a one-dimensional array of integers. This is necessary because each iteration of the `for` obtains the next array in `nums`, beginning with the array specified by `nums[0]`. The inner `for` loop then cycles through each of these arrays, displaying the values of each element.

**Applying the Enhanced for**

Since the for-each style `for` can only cycle through an array sequentially, from start to finish, you might think that its use is limited, but this is not true. A large number of algorithms require exactly this mechanism. One of the most common is searching. For example, the following program uses a `for` loop to search an unsorted array for a value. It stops if the value is found.

```java
// Search an array using for-each style for.
class Search {
    public static void main(String args[]) {
        int nums[] = { 6, 8, 3, 7, 5, 6, 1, 4 };
        int val = 5;
        boolean found = false;

        // use for-each style for to search nums for val
        for(int x : nums) {
            if(x == val) {
                found = true;
                break;
            }
        }

        if(found)
            System.out.println("Value found!");
    }
}
```

The for-each style `for` is an excellent choice in this application because searching an unsorted array involves examining each element in sequence. (Of course, if the array were sorted, a binary search could be used, which would require a different style loop.) Other types of applications that benefit from for-each style loops include computing an average, finding the minimum or maximum of a set, looking for duplicates, and so on.

Although we have been using arrays in the examples in this chapter, the for-each style `for` is especially useful when operating on collections defined by the Collections Framework, which is described in Part II. More generally, the `for` can
cycle through the elements of any collection of objects, as long as that collection satisfies a certain set of constraints, which are described in Chapter 19.

**Nested Loops**

Like all other programming languages, Java allows loops to be nested. That is, one loop may be inside another. For example, here is a program that nests `for` loops:

```java
// Loops may be nested.
class Nested {
    public static void main(String args[]) {
        int i, j;

        for(i=0; i<10; i++) {
            for(j=i; j<10; j++)
                System.out.print(".");
            System.out.println();
        }
    }
}
```

The output produced by this program is shown here:

```
...........
...........
...........
...........
...........
...........
...........
......
.......
...
```

**Jump Statements**

Java supports three jump statements: **break**, **continue**, and **return**. These statements transfer control to another part of your program. Each is examined here.

**NOTE** In addition to the jump statements discussed here, Java supports one other way that you can change your program’s flow of execution: through exception handling. Exception handling provides a structured method by which run-time errors can be trapped and handled by your program. It is supported by the
keywords **try, catch, throw, throws,** and **finally.** In essence, the exception handling mechanism allows your program to perform a nonlocal branch. Since exception handling is a large topic, it is discussed in its own chapter, **Chapter 10.**

**Using break**

In Java, the **break** statement has three uses. First, as you have seen, it terminates a statement sequence in a **switch** statement. Second, it can be used to exit a loop. Third, it can be used as a “civilized” form of goto. The last two uses are explained here.

**Using break to Exit a Loop**

By using **break**, you can force immediate termination of a loop, bypassing the conditional expression and any remaining code in the body of the loop. When a **break** statement is encountered inside a loop, the loop is terminated and program control resumes at the next statement following the loop. Here is a simple example:

```java
// Using break to exit a loop.
class BreakLoop {
    public static void main(String args[]) {
        for(int i=0; i<100; i++) {
            if(i == 10) break; // terminate loop if i is 10
            System.out.println("i: " + i);
        }
        System.out.println("Loop complete.");
    }
}
```

This program generates the following output:

```
i: 0
i: 1
i: 2
i: 3
i: 4
i: 5
i: 6
i: 7
i: 8
i: 9
Loop complete.
```
As you can see, although the for loop is designed to run from 0 to 99, the break statement causes it to terminate early, when i equals 10.

The break statement can be used with any of Java’s loops, including intentionally infinite loops. For example, here is the preceding program coded by use of a while loop. The output from this program is the same as just shown.

```java
// Using break to exit a while loop.
class BreakLoop2 {
    public static void main(String args[]) {
        int i = 0;

        while(i < 100) {
            if(i == 10) break; // terminate loop if i is 10
            System.out.println("i: " + i);
            i++;
        }
        System.out.println("Loop complete.");
    }
}
```

When used inside a set of nested loops, the break statement will only break out of the innermost loop. For example:

```java
// Using break with nested loops.
class BreakLoop3 {
    public static void main(String args[]) {
        for(int i=0; i<3; i++) {
            System.out.print("Pass " + i + ": ");
            for(int j=0; j<100; j++) {
                if(j == 10) break; // terminate loop if j is 10
                System.out.print(j + " ");
            }
            System.out.println();
        }
        System.out.println("Loops complete.");
    }
}
```

This program generates the following output:

```
Pass 0: 0 1 2 3 4 5 6 7 8 9
Pass 1: 0 1 2 3 4 5 6 7 8 9
Pass 2: 0 1 2 3 4 5 6 7 8 9
Loops complete.
```
As you can see, the `break` statement in the inner loop only causes termination of that loop. The outer loop is unaffected.

Here are two other points to remember about `break`. First, more than one `break` statement may appear in a loop. However, be careful. Too many `break` statements have the tendency to destruct your code. Second, the `break` that terminates a `switch` statement affects only that `switch` statement and not any enclosing loops.

**REMEMBER** `break` was not designed to provide the normal means by which a loop is terminated. The loop’s conditional expression serves this purpose. The `break` statement should be used to cancel a loop only when some sort of special situation occurs.

**Using `break` as a Form of Goto**

In addition to its uses with the `switch` statement and loops, the `break` statement can also be employed by itself to provide a “civilized” form of the goto statement. Java does not have a goto statement because it provides a way to branch in an arbitrary and unstructured manner. This usually makes goto-ridden code hard to understand and hard to maintain. It also prohibits certain compiler optimizations. There are, however, a few places where the goto is a valuable and legitimate construct for flow control. For example, the goto can be useful when you are exiting from a deeply nested set of loops. To handle such situations, Java defines an expanded form of the `break` statement. By using this form of `break`, you can, for example, break out of one or more blocks of code. These blocks need not be part of a loop or a `switch`. They can be any block. Further, you can specify precisely where execution will resume, because this form of `break` works with a label. As you will see, `break` gives you the benefits of a goto without its problems.

The general form of the labeled `break` statement is shown here:

```java
break label;
```

Most often, `label` is the name of a label that identifies a block of code. This can be a stand-alone block of code but it can also be a block that is the target of another statement. When this form of `break` executes, control is transferred out of the named block. The labeled block must enclose the `break` statement, but it does not need to be the immediately enclosing block. This means, for example, that you can use a labeled `break` statement to exit from a set of nested blocks. But you cannot use `break` to transfer control out of a block that does not enclose the `break` statement.

To name a block, put a label at the start of it. A `label` is any valid Java identifier followed by a colon. Once you have labeled a block, you can then use this label as the target of a `break` statement. Doing so causes execution to resume at the *end* of the labeled block. For example, the following program shows three nested blocks,
each with its own label. The `break` statement causes execution to jump forward, past the end of the block labeled `second`, skipping the two `println()` statements.

```java
// Using break as a civilized form of goto.
class Break {
    public static void main(String args[]) {
        boolean t = true;

        first: {
            second: {
                third: {
                    System.out.println("Before the break.");
                    if(t) break second; // break out of second block
                    System.out.println("This won't execute");
                }
                System.out.println("This won't execute");
            }
            System.out.println("This is after second block.");
        }
    }
}
```

Running this program generates the following output:

```
Before the break.
This is after second block.
```

One of the most common uses for a labeled `break` statement is to exit from nested loops. For example, in the following program, the outer loop executes only once:

```java
// Using break to exit from nested loops
class BreakLoop4 {
    public static void main(String args[]) {
        for(int i=0; i<3; i++) {
            System.out.print("Pass " + i + ": ");
            for(int j=0; j<100; j++) {
                if(j == 10) break outer; // exit both loops
                System.out.print(j + " ");
            }
            System.out.println("This will not print");
        }
        System.out.println("Loops complete.");
    }
}
```
This program generates the following output:

```
Pass 0: 0 1 2 3 4 5 6 7 8 9 Loops complete.
```

As you can see, when the inner loop breaks to the outer loop, both loops have been terminated. Notice that this example labels the `for` statement, which has a block of code as its target.

Keep in mind that you cannot break to any label which is not defined for an enclosing block. For example, the following program is invalid and will not compile:

```java
// This program contains an error.
class BreakErr {
    public static void main(String args[]) {
        one: for(int i=0; i<3; i++) {
            System.out.print("Pass "+i+": ");
        }

        for(int j=0; j<100; j++) {
            if(j == 10) break one; // WRONG
            System.out.print(j + " ");
        }
    }
}
```

Since the loop labeled `one` does not enclose the `break` statement, it is not possible to transfer control out of that block.

### Using `continue`

Sometimes it is useful to force an early iteration of a loop. That is, you might want to continue running the loop but stop processing the remainder of the code in its body for this particular iteration. This is, in effect, a goto just past the body of the loop, to the loop’s end. The `continue` statement performs such an action. In `while` and `do-while` loops, a `continue` statement causes control to be transferred directly to the conditional expression that controls the loop. In a `for` loop, control goes first to the iteration portion of the `for` statement and then to the conditional expression. For all three loops, any intermediate code is bypassed.

Here is an example program that uses `continue` to cause two numbers to be printed on each line:
// Demonstrate continue.
class Continue {
    public static void main(String args[]) {
        for(int i=0; i<10; i++) {
            System.out.print(i + " ");
            if (i%2 == 0) continue;
            System.out.println(" ");
        }
    }
}

This code uses the % operator to check if i is even. If it is, the loop continues without printing a newline. Here is the output from this program:

0 1
2 3
4 5
6 7
8 9

As with the break statement, continue may specify a label to describe which enclosing loop to continue. Here is an example program that uses continue to print a triangular multiplication table for 0 through 9:

// Using continue with a label.
class ContinueLabel {
    public static void main(String args[]) {
        outer: for (int i=0; i<10; i++) {
            for(int j=0; j<10; j++) {
                if(j > i) {
                    System.out.println();
                    continue outer;
                }
                System.out.print(" ") + (i * j));
            }
        }
        System.out.println();
    }
}

The continue statement in this example terminates the loop counting j and continues with the next iteration of the loop counting i. Here is the output of this program:
Good uses of continue are rare. One reason is that Java provides a rich set of loop statements which fit most applications. However, for those special circumstances in which early iteration is needed, the continue statement provides a structured way to accomplish it.

return
The last control statement is return. The return statement is used to explicitly return from a method. That is, it causes program control to transfer back to the caller of the method. As such, it is categorized as a jump statement. Although a full discussion of return must wait until methods are discussed in Chapter 6, a brief look at return is presented here.

At any time in a method, the return statement can be used to cause execution to branch back to the caller of the method. Thus, the return statement immediately terminates the method in which it is executed. The following example illustrates this point. Here, return causes execution to return to the Java run-time system, since it is the run-time system that calls main():

```java
// Demonstrate return.
class Return {
    public static void main(String args[]) {
        boolean t = true;

        System.out.println("Before the return.");

        if(t) return; // return to caller

        System.out.println("This won't execute.");
    }
}
```

The output from this program is shown here:
As you can see, the final `println()` statement is not executed. As soon as `return` is executed, control passes back to the caller.

One last point: In the preceding program, the `if(t)` statement is necessary. Without it, the Java compiler would flag an “unreachable code” error because the compiler would know that the last `println()` statement would never be executed. To prevent this error, the `if` statement is used here to trick the compiler for the sake of this demonstration.
The class is at the core of Java. It is the logical construct upon which the entire Java language is built because it defines the shape and nature of an object. As such, the class forms the basis for object-oriented programming in Java. Any concept you wish to implement in a Java program must be encapsulated within a class.

Because the class is so fundamental to Java, this and the next few chapters will be devoted to it. Here, you will be introduced to the basic elements of a class and learn how a class can be used to create objects. You will also learn about methods, constructors, and the `this` keyword.

**Class Fundamentals**

Classes have been used since the beginning of this book. However, until now, only the most rudimentary form of a class has been shown. The classes created in the preceding chapters primarily exist simply to encapsulate the `main()` method, which has been used to demonstrate the basics of the Java syntax. As you will see, classes are substantially more powerful than the limited ones presented so far.

Perhaps the most important thing to understand about a class is that it defines a new data type. Once defined, this new type can be used to create objects of that type. Thus, a class is a template for an object, and an object is an instance of a class. Because an object is an instance of a class, you will often see the two words `object` and `instance` used interchangeably.

**The General Form of a Class**

When you define a class, you declare its exact form and nature. You do this by specifying the data that it contains and the code that operates on that data. While very simple classes may contain only code or only data, most real-world classes contain both. As you will see, a class’ code defines the interface to its data.

A class is declared by use of the `class` keyword. The classes that have been used up to this point are actually very limited examples of its complete form. Classes can (and usually do) get much more complex. A simplified general form of a `class` definition is shown here:
The data, or variables, defined within a class are called instance variables. The code is contained within methods. Collectively, the methods and variables defined within a class are called members of the class. In most classes, the instance variables are acted upon and accessed by the methods defined for that class. Thus, as a general rule, it is the methods that determine how a class’ data can be used.

Variables defined within a class are called instance variables because each instance of the class (that is, each object of the class) contains its own copy of these variables. Thus, the data for one object is separate and unique from the data for another. We will come back to this point shortly, but it is an important concept to learn early.

All methods have the same general form as main(), which we have been using thus far. However, most methods will not be specified as static or public. Notice that the general form of a class does not specify a main() method. Java classes do not need to have a main() method. You only specify one if that class is the starting point for your program. Further, some kinds of Java applications don’t require a main() method at all.

A Simple Class
Let’s begin our study of the class with a simple example. Here is a class called Box that defines three instance variables: width, height, and depth. Currently, Box does
not contain any methods (but some will be added soon).

class Box {
    double width;
    double height;
    double depth;
}

As stated, a class defines a new type of data. In this case, the new data type is called **Box**. You will use this name to declare objects of type **Box**. It is important to remember that a class declaration only creates a template; it does not create an actual object. Thus, the preceding code does not cause any objects of type **Box** to come into existence.

To actually create a **Box** object, you will use a statement like the following:

```
Box mybox = new Box(); // create a Box object called mybox
```

After this statement executes, **mybox** will refer to an instance of **Box**. Thus, it will have “physical” reality. For the moment, don’t worry about the details of this statement.

As mentioned earlier, each time you create an instance of a class, you are creating an object that contains its own copy of each instance variable defined by the class. Thus, every **Box** object will contain its own copies of the instance variables **width**, **height**, and **depth**. To access these variables, you will use the `dot (.)` operator. The dot operator links the name of the object with the name of an instance variable. For example, to assign the **width** variable of **mybox** the value 100, you would use the following statement:

```
mybox.width = 100;
```

This statement tells the compiler to assign the copy of **width** that is contained within the **mybox** object the value of 100. In general, you use the dot operator to access both the instance variables and the methods within an object. One other point: Although commonly referred to as the dot operator, the formal specification for Java categorizes the . as a separator. However, since the use of the term “dot operator” is widespread, it is used in this book.

Here is a complete program that uses the **Box** class:
/* A program that uses the Box class. 

Call this file BoxDemo.java */
class Box {
    double width;
    double height;
    double depth;
}

// This class declares an object of type Box.
class BoxDemo {
    public static void main(String args[]) {
        Box mybox = new Box();
        double vol;

        // assign values to mybox's instance variables
        mybox.width = 10;
        mybox.height = 20;
        mybox.depth = 15;

        // compute volume of box
        vol = mybox.width * mybox.height * mybox.depth;

        System.out.println("Volume is "+ vol);
    }
}

You should call the file that contains this program BoxDemo.java, because the main() method is in the class called BoxDemo, not the class called Box. When you compile this program, you will find that two .class files have been created, one for Box and one for BoxDemo. The Java compiler automatically puts each class into its own .class file. It is not necessary for both the Box and the BoxDemo class to actually be in the same source file. You could put each class in its own file, called Box.java and BoxDemo.java, respectively.

To run this program, you must execute BoxDemo.class. When you do, you will see the following output:

Volume is 3000.0

As stated earlier, each object has its own copies of the instance variables. This means that if you have two Box objects, each has its own copy of depth, width, and height. It is important to understand that changes to the instance variables of one object have no effect on the instance variables of another. For example, the
following program declares two **Box** objects:

```java
// This program declares two Box objects.

class Box {
    double width;
    double height;
    double depth;
}

class BoxDemo2 {
    public static void main(String args[]) {
        Box mybox1 = new Box();
        Box mybox2 = new Box();
        double vol;

        // assign values to mybox1's instance variables
        mybox1.width = 10;
        mybox1.height = 20;
        mybox1.depth = 15;

        /* assign different values to mybox2's 
           instance variables */
        mybox2.width = 3;
        mybox2.height = 6;
        mybox2.depth = 9;

        // compute volume of first box
        vol = mybox1.width * mybox1.height * mybox1.depth;
        System.out.println("Volume is " + vol);

        // compute volume of second box
        vol = mybox2.width * mybox2.height * mybox2.depth;
        System.out.println("Volume is " + vol);
    }
}
```

The output produced by this program is shown here:

```
Volume is 3000.0
Volume is 162.0
```

As you can see, **mybox1**’s data is completely separate from the data contained in **mybox2**.
Declaring Objects

As just explained, when you create a class, you are creating a new data type. You can use this type to declare objects of that type. However, obtaining objects of a class is a two-step process. First, you must declare a variable of the class type. This variable does not define an object. Instead, it is simply a variable that can refer to an object. Second, you must acquire an actual, physical copy of the object and assign it to that variable. You can do this using the new operator. The new operator dynamically allocates (that is, allocates at run time) memory for an object and returns a reference to it. This reference is, essentially, the address in memory of the object allocated by new. This reference is then stored in the variable. Thus, in Java, all class objects must be dynamically allocated. Let’s look at the details of this procedure.

In the preceding sample programs, a line similar to the following is used to declare an object of type Box:

```java
Box mybox = new Box();
```

This statement combines the two steps just described. It can be rewritten like this to show each step more clearly:

```java
Box mybox; // declare reference to object
mybox = new Box(); // allocate a Box object
```

The first line declares mybox as a reference to an object of type Box. At this point, mybox does not yet refer to an actual object. The next line allocates an object and assigns a reference to it to mybox. After the second line executes, you can use mybox as if it were a Box object. But in reality, mybox simply holds, in essence, the memory address of the actual Box object. The effect of these two lines of code is depicted in Figure 6-1.
A Closer Look at new

As just explained, the new operator dynamically allocates memory for an object. In the context of an assignment, it has this general form:

\[
\text{class-var} = \text{new classname}();
\]

Here, class-var is a variable of the class type being created. The classname is the name of the class that is being instantiated. The class name followed by parentheses specifies the constructor for the class. A constructor defines what occurs when an object of a class is created. Constructors are an important part of all classes and have many significant attributes. Most real-world classes explicitly define their own constructors within their class definition. However, if no explicit constructor is specified, then Java will automatically supply a default constructor. This is the case with Box. For now, we will use the default constructor. Soon, you will see how to define your own constructors.

At this point, you might be wondering why you do not need to use new for such things as integers or characters. The answer is that Java’s primitive types are not implemented as objects. Rather, they are implemented as “normal” variables. This is done in the interest of efficiency. As you will see, objects have many features and attributes that require Java to treat them differently than it treats the primitive types. By not applying the same overhead to the primitive types that applies to objects, Java can implement the primitive types more efficiently. Later, you will see object versions of the primitive types that are available for your use in those situations in
which complete objects of these types are needed.

It is important to understand that `new` allocates memory for an object during run time. The advantage of this approach is that your program can create as many or as few objects as it needs during the execution of your program. However, since memory is finite, it is possible that `new` will not be able to allocate memory for an object because insufficient memory exists. If this happens, a run-time exception will occur. (You will learn how to handle exceptions in Chapter 10.) For the sample programs in this book, you won’t need to worry about running out of memory, but you will need to consider this possibility in real-world programs that you write.

Let’s once again review the distinction between a class and an object. A class creates a new data type that can be used to create objects. That is, a class creates a logical framework that defines the relationship between its members. When you declare an object of a class, you are creating an instance of that class. Thus, a class is a logical construct. An object has physical reality. (That is, an object occupies space in memory.) It is important to keep this distinction clearly in mind.

### Assigning Object Reference Variables

Object reference variables act differently than you might expect when an assignment takes place. For example, what do you think the following fragment does?

```java
Box b1 = new Box();
Box b2 = b1;
```

You might think that `b2` is being assigned a reference to a copy of the object referred to by `b1`. That is, you might think that `b1` and `b2` refer to separate and distinct objects. However, this would be wrong. Instead, after this fragment executes, `b1` and `b2` will both refer to the *same* object. The assignment of `b1` to `b2` did not allocate any memory or copy any part of the original object. It simply makes `b2` refer to the same object as does `b1`. Thus, any changes made to the object through `b2` will affect the object to which `b1` is referring, since they are the same object.

This situation is depicted here: 

![Diagram showing object reference variables](image)
Although \texttt{b1} and \texttt{b2} both refer to the same object, they are not linked in any other way. For example, a subsequent assignment to \texttt{b1} will simply \textit{unhook} \texttt{b1} from the original object without affecting the object or affecting \texttt{b2}. For example:

```java
Box b1 = new Box();
Box b2 = b1;
// ...
b1 = null;
```

Here, \texttt{b1} has been set to \texttt{null}, but \texttt{b2} still points to the original object.

\textbf{REMEMBER} When you assign one object reference variable to another object reference variable, you are not creating a copy of the object, you are only making a copy of the reference.

\section*{Introducing Methods}

As mentioned at the beginning of this chapter, classes usually consist of two things: instance variables and methods. The topic of methods is a large one because Java gives them so much power and flexibility. In fact, much of the next chapter is devoted to methods. However, there are some fundamentals that you need to learn now so that you can begin to add methods to your classes.

This is the general form of a method:

\begin{verbatim}
    type name(parameter-list) {
        // body of method
    }
\end{verbatim}

Here, \textit{type} specifies the type of data returned by the method. This can be any valid type, including class types that you create. If the method does not return a value, its return type must be \texttt{void}. The name of the method is specified by \textit{name}. This can be any legal identifier other than those already used by other items within the current scope. The \textit{parameter-list} is a sequence of type and identifier pairs separated by commas. Parameters are essentially variables that receive the value of the arguments passed to the method when it is called. If the method has no parameters, then the parameter list will be empty.

Methods that have a return type other than \texttt{void} return a value to the calling routine using the following form of the \texttt{return} statement:

\begin{verbatim}
    return value;
\end{verbatim}
Here, \textit{value} is the value returned.

In the next few sections, you will see how to create various types of methods, including those that take parameters and those that return values.

**Adding a Method to the Box Class**

Although it is perfectly fine to create a class that contains only data, it rarely happens. Most of the time, you will use methods to access the instance variables defined by the class. In fact, methods define the interface to most classes. This allows the class implementor to hide the specific layout of internal data structures behind cleaner method abstractions. In addition to defining methods that provide access to data, you can also define methods that are used internally by the class itself.

Let’s begin by adding a method to the \texttt{Box} class. It may have occurred to you while looking at the preceding programs that the computation of a box’s volume was something that was best handled by the \texttt{Box} class rather than the \texttt{BoxDemo} class. After all, since the volume of a box is dependent upon the size of the box, it makes sense to have the \texttt{Box} class compute it. To do this, you must add a method to \texttt{Box}, as shown here:
This program includes a method inside the box class.

class Box {
    double width;
    double height;
    double depth;

    // display volume of a box
    void volume() {
        System.out.print("Volume is ");
        System.out.println(width * height * depth);
    }
}

class BoxDemo3 {
    public static void main(String args[]) {
        Box mybox1 = new Box();
        Box mybox2 = new Box();

        // assign values to mybox1's instance variables
        mybox1.width = 10;
        mybox1.height = 20;
        mybox1.depth = 15;
        /* assign different values to mybox2's
         * instance variables */
        mybox2.width = 3;
        mybox2.height = 6;
        mybox2.depth = 9;

        // display volume of first box
        mybox1.volume();

        // display volume of second box
        mybox2.volume();
    }
}

This program generates the following output, which is the same as the previous version.

    Volume is 3000.0
    Volume is 162.0

Look closely at the following two lines of code:
mybox1.volume();
mybox2.volume();

The first line here invokes the `volume()` method on `mybox1`. That is, it calls `volume()` relative to the `mybox1` object, using the object’s name followed by the dot operator. Thus, the call to `mybox1.volume()` displays the volume of the box defined by `mybox1`, and the call to `mybox2.volume()` displays the volume of the box defined by `mybox2`. Each time `volume()` is invoked, it displays the volume for the specified box.

If you are unfamiliar with the concept of calling a method, the following discussion will help clear things up. When `mybox1.volume()` is executed, the Java run-time system transfers control to the code defined inside `volume()`. After the statements inside `volume()` have executed, control is returned to the calling routine, and execution resumes with the line of code following the call. In the most general sense, a method is Java’s way of implementing subroutines.

There is something very important to notice inside the `volume()` method: the instance variables `width`, `height`, and `depth` are referred to directly, without preceding them with an object name or the dot operator. When a method uses an instance variable that is defined by its class, it does so directly, without explicit reference to an object and without use of the dot operator. This is easy to understand if you think about it. A method is always invoked relative to some object of its class. Once this invocation has occurred, the object is known. Thus, within a method, there is no need to specify the object a second time. This means that `width`, `height`, and `depth` inside `volume()` implicitly refer to the copies of those variables found in the object that invokes `volume()`.

Let’s review: When an instance variable is accessed by code that is not part of the class in which that instance variable is defined, it must be done through an object, by use of the dot operator. However, when an instance variable is accessed by code that is part of the same class as the instance variable, that variable can be referred to directly. The same thing applies to methods.

**Returning a Value**

While the implementation of `volume()` does move the computation of a box’s volume inside the `Box` class where it belongs, it is not the best way to do it. For example, what if another part of your program wanted to know the volume of a box, but not display its value? A better way to implement `volume()` is to have it compute the volume of the box and return the result to the caller. The following example, an improved version of the preceding program, does just that:
As you can see, when `volume()` is called, it is put on the right side of an assignment statement. On the left is a variable, in this case `vol`, that will receive the value returned by `volume()`. Thus, after
vol = mybox1.volume();

executes, the value of mybox1.volume() is 3,000 and this value then is stored in vol.

There are two important things to understand about returning values:

- The type of data returned by a method must be compatible with the return type specified by the method. For example, if the return type of some method is boolean, you could not return an integer.
- The variable receiving the value returned by a method (such as vol, in this case) must also be compatible with the return type specified for the method.

One more point: The preceding program can be written a bit more efficiently because there is actually no need for the vol variable. The call to volume() could have been used in the println() statement directly, as shown here:

System.out.println("Volume is" + mybox1.volume());

In this case, when println() is executed, mybox1.volume() will be called automatically and its value will be passed to println().

Adding a Method That Takes Parameters

While some methods don’t need parameters, most do. Parameters allow a method to be generalized. That is, a parameterized method can operate on a variety of data and/or be used in a number of slightly different situations. To illustrate this point, let’s use a very simple example. Here is a method that returns the square of the number 10:

```
int square()
{
    return 10 * 10;
}
```

While this method does, indeed, return the value of 10 squared, its use is very limited. However, if you modify the method so that it takes a parameter, as shown next, then you can make square() much more useful.

```
int square(int i)
{
    return i * i;
}
```
Now, `square()` will return the square of whatever value it is called with. That is, `square()` is now a general-purpose method that can compute the square of any integer value, rather than just 10.

Here is an example:

```java
int x, y;
x = square(5); // x equals 25
x = square(9); // x equals 81
y = 2;
x = square(y); // x equals 4
```

In the first call to `square()`, the value 5 will be passed into parameter `i`. In the second call, `i` will receive the value 9. The third invocation passes the value of `y`, which is 2 in this example. As these examples show, `square()` is able to return the square of whatever data it is passed.

It is important to keep the two terms `parameter` and `argument` straight. A `parameter` is a variable defined by a method that receives a value when the method is called. For example, in `square()`, `i` is a parameter. An `argument` is a value that is passed to a method when it is invoked. For example, `square(100)` passes 100 as an argument. Inside `square()`, the parameter `i` receives that value.

You can use a parameterized method to improve the `Box` class. In the preceding examples, the dimensions of each box had to be set separately by use of a sequence of statements, such as:

```java
mybox1.width = 10;
mybox1.height = 20;
mybox1.depth = 15;
```

While this code works, it is troubling for two reasons. First, it is clumsy and error prone. For example, it would be easy to forget to set a dimension. Second, in well-designed Java programs, instance variables should be accessed only through methods defined by their class. In the future, you can change the behavior of a method, but you can’t change the behavior of an exposed instance variable.

Thus, a better approach to setting the dimensions of a box is to create a method that takes the dimensions of a box in its parameters and sets each instance variable appropriately. This concept is implemented by the following program:
// This program uses a parameterized method.

class Box {
    double width;
    double height;
    double depth;

    // compute and return volume
    double volume() {
        return width * height * depth;
    }

    // sets dimensions of box
    void setDim(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }
}

class BoxDemo5 {
    public static void main(String args[]) {
        Box mybox1 = new Box();
        Box mybox2 = new Box();
        double vol;

        // initialize each box
        mybox1.setDim(10, 20, 15);
        mybox2.setDim(3, 6, 9);

        // get volume of first box
        vol = mybox1.volume();
        System.out.println("Volume is " + vol);

        // get volume of second box
        vol = mybox2.volume();
        System.out.println("Volume is " + vol);
    }
}

As you can see, the setDim() method is used to set the dimensions of each box. For example, when

mybox1.setDim(10, 20, 15);
is executed, 10 is copied into parameter $w$, 20 is copied into $h$, and 15 is copied into $d$. Inside `setDim()` the values of $w$, $h$, and $d$ are then assigned to `width`, `height`, and `depth`, respectively.

For many readers, the concepts presented in the preceding sections will be familiar. However, if such things as method calls, arguments, and parameters are new to you, then you might want to take some time to experiment before moving on. The concepts of the method invocation, parameters, and return values are fundamental to Java programming.

**Constructors**

It can be tedious to initialize all of the variables in a class each time an instance is created. Even when you add convenience functions like `setDim()`, it would be simpler and more concise to have all of the setup done at the time the object is first created. Because the requirement for initialization is so common, Java allows objects to initialize themselves when they are created. This automatic initialization is performed through the use of a constructor.

A constructor initializes an object immediately upon creation. It has the same name as the class in which it resides and is syntactically similar to a method. Once defined, the constructor is automatically called when the object is created, before the `new` operator completes. Constructors look a little strange because they have no return type, not even `void`. This is because the implicit return type of a class’ constructor is the class type itself. It is the constructor’s job to initialize the internal state of an object so that the code creating an instance will have a fully initialized, usable object immediately.

You can rework the `Box` example so that the dimensions of a box are automatically initialized when an object is constructed. To do so, replace `setDim()` with a constructor. Let’s begin by defining a simple constructor that sets the dimensions of each box to the same values. This version is shown here:
/* Here, Box uses a constructor to initialize the
dimensions of a box.
*/

class Box {
    double width;
    double height;
    double depth;

    // This is the constructor for Box.
    Box() {
        System.out.println("Constructing Box");
        width = 10;
        height = 10;
        depth = 10;
    }

    // compute and return volume
    double volume() {
        return width * height * depth;
    }
}

class BoxDemo6 {
    public static void main(String args[]) {
        // declare, allocate, and initialize Box objects
        Box mybox1 = new Box();
        Box mybox2 = new Box();

        double vol;

        // get volume of first box
        vol = mybox1.volume();
        System.out.println("Volume is " + vol);

        // get volume of second box
        vol = mybox2.volume();
        System.out.println("Volume is " + vol);
    }
}

When this program is run, it generates the following results:
As you can see, both mybox1 and mybox2 were initialized by the Box() constructor when they were created. Since the constructor gives all boxes the same dimensions, 10 by 10 by 10, both mybox1 and mybox2 will have the same volume. The println() statement inside Box() is for the sake of illustration only. Most constructors will not display anything. They will simply initialize an object.

Before moving on, let’s reexamine the new operator. As you know, when you allocate an object, you use the following general form:

    class-var = new classname();

Now you can understand why the parentheses are needed after the class name. What is actually happening is that the constructor for the class is being called. Thus, in the line

    Box mybox1 = new Box();

new Box() is calling the Box() constructor. When you do not explicitly define a constructor for a class, then Java creates a default constructor for the class. This is why the preceding line of code worked in earlier versions of Box that did not define a constructor. When using the default constructor, all non-initialized instance variables will have their default values, which are zero, null, and false, for numeric types, reference types, and boolean, respectively. The default constructor is often sufficient for simple classes, but it usually won’t do for more sophisticated ones. Once you define your own constructor, the default constructor is no longer used.

**Parameterized Constructors**

While the Box() constructor in the preceding example does initialize a Box object, it is not very useful—all boxes have the same dimensions. What is needed is a way to construct Box objects of various dimensions. The easy solution is to add parameters to the constructor. As you can probably guess, this makes it much more useful. For example, the following version of Box defines a parameterized constructor that sets the dimensions of a box as specified by those parameters. Pay special attention to how Box objects are created.
The output from this program is shown here:

Volume is 3000.0
Volume is 162.0

As you can see, each object is initialized as specified in the parameters to its
constructor. For example, in the following line,

```java
Box mybox1 = new Box(10, 20, 15);
```

the values 10, 20, and 15 are passed to the `Box()` constructor when `new` creates the object. Thus, `mybox1`’s copy of `width`, `height`, and `depth` will contain the values 10, 20, and 15, respectively.

### The `this` Keyword

Sometimes a method will need to refer to the object that invoked it. To allow this, Java defines the `this` keyword. `this` can be used inside any method to refer to the current object. That is, `this` is always a reference to the object on which the method was invoked. You can use `this` anywhere a reference to an object of the current class’ type is permitted.

To better understand what `this` refers to, consider the following version of `Box()`:

```java
// A redundant use of this.
Box(double w, double h, double d) {
    this.width = w;
    this.height = h;
    this.depth = d;
}
```

This version of `Box()` operates exactly like the earlier version. The use of `this` is redundant, but perfectly correct. Inside `Box()`, `this` will always refer to the invoking object. While it is redundant in this case, `this` is useful in other contexts, one of which is explained in the next section.

### Instance Variable Hiding

As you know, it is illegal in Java to declare two local variables with the same name inside the same or enclosing scopes. Interestingly, you can have local variables, including formal parameters to methods, which overlap with the names of the class’ instance variables. However, when a local variable has the same name as an instance variable, the local variable hides the instance variable. This is why `width`, `height`, and `depth` were not used as the names of the parameters to the `Box()` constructor inside the `Box` class. If they had been, then `width`, for example, would have referred to the formal parameter, hiding the instance variable `width`. While it is usually easier to simply use different names, there is another way around this situation. Because `this` lets you refer directly to the object, you can use it to resolve any namespace...
collisions that might occur between instance variables and local variables. For example, here is another version of Box(), which uses width, height, and depth for parameter names and then uses this to access the instance variables by the same name:

```java
// Use this to resolve name-space collisions.
Box(double width, double height, double depth) {
    this.width = width;
    this.height = height;
    this.depth = depth;
}
```

A word of caution: The use of this in such a context can sometimes be confusing, and some programmers are careful not to use local variables and formal parameter names that hide instance variables. Of course, other programmers believe the contrary—that it is a good convention to use the same names for clarity, and use this to overcome the instance variable hiding. It is a matter of taste which approach you adopt.

**Garbage Collection**

Since objects are dynamically allocated by using the new operator, you might be wondering how such objects are destroyed and their memory released for later reallocation. In some languages, such as traditional C++, dynamically allocated objects must be manually released by use of a delete operator. Java takes a different approach; it handles deallocation for you automatically. The technique that accomplishes this is called garbage collection. It works like this: when no references to an object exist, that object is assumed to be no longer needed, and the memory occupied by the object can be reclaimed. There is no need to explicitly destroy objects. Garbage collection only occurs sporadically (if at all) during the execution of your program. It will not occur simply because one or more objects exist that are no longer used. Furthermore, different Java run-time implementations will take varying approaches to garbage collection, but for the most part, you should not have to think about it while writing your programs.

**A Stack Class**

While the Box class is useful to illustrate the essential elements of a class, it is of little practical value. To show the real power of classes, this chapter will conclude with a more sophisticated example. As you recall from the discussion of object-
oriented programming (OOP) presented in Chapter 2, one of OOP’s most important benefits is the encapsulation of data and the code that manipulates that data. As you have seen, the class is the mechanism by which encapsulation is achieved in Java. By creating a class, you are creating a new data type that defines both the nature of the data being manipulated and the routines used to manipulate it. Further, the methods define a consistent and controlled interface to the class’ data. Thus, you can use the class through its methods without having to worry about the details of its implementation or how the data is actually managed within the class. In a sense, a class is like a “data engine.” No knowledge of what goes on inside the engine is required to use the engine through its controls. In fact, since the details are hidden, its inner workings can be changed as needed. As long as your code uses the class through its methods, internal details can change without causing side effects outside the class.

To see a practical application of the preceding discussion, let’s develop one of the archetypal examples of encapsulation: the stack. A stack stores data using first-in, last-out ordering. That is, a stack is like a stack of plates on a table—the first plate put down on the table is the last plate to be used. Stacks are controlled through two operations traditionally called push and pop. To put an item on top of the stack, you will use push. To take an item off the stack, you will use pop. As you will see, it is easy to encapsulate the entire stack mechanism.

Here is a class called Stack that implements a stack for up to ten integers:
As you can see, the *Stack* class defines two data items, two methods, and a constructor. The stack of integers is held by the array `stck`. This array is indexed by the variable `tos`, which always contains the index of the top of the stack. The `Stack()` constructor initializes `tos` to –1, which indicates an empty stack. The method `push()` puts an item on the stack. To retrieve an item, call `pop()`. Since access to the stack is through `push()` and `pop()`, the fact that the stack is held in an array is actually not relevant to using the stack. For example, the stack could be held in a more complicated data structure, such as a linked list, yet the interface defined by `push()` and `pop()` would remain the same.

The class `TestStack`, shown here, demonstrates the *Stack* class. It creates two integer stacks, pushes some values onto each, and then pops them off.
class TestStack {
    public static void main(String args[]) {
        Stack mystack1 = new Stack();
        Stack mystack2 = new Stack();

        // push some numbers onto the stack
        for(int i=0; i<10; i++) mystack1.push(i);
        for(int i=10; i<20; i++) mystack2.push(i);

        // pop those numbers off the stack
        System.out.println("Stack in mystack1:");
        for(int i=0; i<10; i++)
            System.out.println(mystack1.pop());

        System.out.println("Stack in mystack2:");
        for(int i=0; i<10; i++)
            System.out.println(mystack2.pop());
    }
}

This program generates the following output:

Stack in mystack1:
 9
 8
 7
 6
 5
 4
 3
 2
 1
 0

Stack in mystack2:
 19
 18
 17
 16
 15
 14
 13
 12
 11
10
As you can see, the contents of each stack are separate.

One last point about the **Stack** class. As it is currently implemented, it is possible for the array that holds the stack, **stck**, to be altered by code outside of the **Stack** class. This leaves **Stack** open to misuse or mischief. In the next chapter, you will see how to remedy this situation.
This chapter continues the discussion of methods and classes begun in the preceding chapter. It examines several topics relating to methods, including overloading, parameter passing, and recursion. The chapter then returns to the class, discussing access control, the use of the keyword `static`, and one of Java’s most important built-in classes: `String`.

### Overloading Methods

In Java, it is possible to define two or more methods within the same class that share the same name, as long as their parameter declarations are different. When this is the case, the methods are said to be overloaded, and the process is referred to as method overloading. Method overloading is one of the ways that Java supports polymorphism. If you have never used a language that allows the overloading of methods, then the concept may seem strange at first. But as you will see, method overloading is one of Java’s most exciting and useful features.

When an overloaded method is invoked, Java uses the type and/or number of arguments as its guide to determine which version of the overloaded method to actually call. Thus, overloaded methods must differ in the type and/or number of their parameters. While overloaded methods may have different return types, the return type alone is insufficient to distinguish two versions of a method. When Java encounters a call to an overloaded method, it simply executes the version of the method whose parameters match the arguments used in the call.

Here is a simple example that illustrates method overloading:
// Demonstrate method overloading.
class OverloadDemo {
    void test() {
        System.out.println("No parameters");
    }

    // Overload test for one integer parameter.
    void test(int a) {
        System.out.println("a: " + a);
    }

    // Overload test for two integer parameters.
    void test(int a, int b) {
        System.out.println("a and b: " + a + " " + b);
    }

    // Overload test for a double parameter
    double test(double a) {
        System.out.println("double a: " + a);
        return a*a;
    }
}

class Overload {
    public static void main(String args[]) {
        OverloadDemo ob = new OverloadDemo();
        double result;

        // call all versions of test()
        ob.test();
        ob.test(10);
        ob.test(10, 20);
        result = ob.test(123.25);
        System.out.println("Result of ob.test(123.25): " + result);
    }
}

This program generates the following output:

No parameters
a: 10
a and b: 10 20
double a: 123.25
Result of ob.test(123.25): 15190.5625

As you can see, test() is overloaded four times. The first version takes no
parameters, the second takes one integer parameter, the third takes two integer parameters, and the fourth takes one double parameter. The fact that the fourth version of test() also returns a value is of no consequence relative to overloading, since return types do not play a role in overload resolution.

When an overloaded method is called, Java looks for a match between the arguments used to call the method and the method’s parameters. However, this match need not always be exact. In some cases, Java’s automatic type conversions can play a role in overload resolution. For example, consider the following program:

```java
// Automatic type conversions apply to overloading.
class OverloadDemo {
    void test() {
        System.out.println("No parameters");
    }

    // Overload test for two integer parameters.
    void test(int a, int b) {
        System.out.println("a and b: " + a + " " + b);
    }

    // Overload test for a double parameter
    void test(double a) {
        System.out.println("Inside test(double) a: " + a);
    }
}

class Overload {
    public static void main(String args[]) {
        OverloadDemo ob = new OverloadDemo();
        int i = 88;

        ob.test();
        ob.test(10, 20);

        ob.test(i); // this will invoke test(double)
        ob.test(123.2); // this will invoke test(double)
    }
}
```

This program generates the following output:
As you can see, this version of OverloadDemo does not define test(int). Therefore, when test() is called with an integer argument inside Overload, no matching method is found. However, Java can automatically convert an integer into a double, and this conversion can be used to resolve the call. Therefore, after test(int) is not found, Java elevates i to double and then calls test(double). Of course, if test(int) had been defined, it would have been called instead. Java will employ its automatic type conversions only if no exact match is found.

Method overloading supports polymorphism because it is one way that Java implements the “one interface, multiple methods” paradigm. To understand how, consider the following. In languages that do not support method overloading, each method must be given a unique name. However, frequently you will want to implement essentially the same method for different types of data. Consider the absolute value function. In languages that do not support overloading, there are usually three or more versions of this function, each with a slightly different name. For instance, in C, the function abs() returns the absolute value of an integer, labs() returns the absolute value of a long integer, and fabs() returns the absolute value of a floating-point value. Since C does not support overloading, each function has its own name, even though all three functions do essentially the same thing. This makes the situation more complex, conceptually, than it actually is. Although the underlying concept of each function is the same, you still have three names to remember. This situation does not occur in Java, because each absolute value method can use the same name. Indeed, Java’s standard class library includes an absolute value method, called abs(). This method is overloaded by Java’s Math class to handle all numeric types. Java determines which version of abs() to call based upon the type of argument.

The value of overloading is that it allows related methods to be accessed by use of a common name. Thus, the name abs represents the general action that is being performed. It is left to the compiler to choose the right specific version for a particular circumstance. You, the programmer, need only remember the general operation being performed. Through the application of polymorphism, several names have been reduced to one. Although this example is fairly simple, if you expand the concept, you can see how overloading can help you manage greater complexity.

When you overload a method, each version of that method can perform any activity you desire. There is no rule stating that overloaded methods must relate to one another. However, from a stylistic point of view, method overloading implies a
relationship. Thus, while you can use the same name to overload unrelated methods, you should not. For example, you could use the name `sqr` to create methods that return the square of an integer and the square root of a floating-point value. But these two operations are fundamentally different. Applying method overloading in this manner defeats its original purpose. In practice, you should only overload closely related operations.

**Overloading Constructors**

In addition to overloading normal methods, you can also overload constructor methods. In fact, for most real-world classes that you create, overloaded constructors will be the norm, not the exception. To understand why, let’s return to the `Box` class developed in the preceding chapter. Following is the latest version of `Box`:

```java
class Box {
    double width;
    double height;
    double depth;

    // This is the constructor for Box.
    Box(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }

    // compute and return volume
    double volume() {
        return width * height * depth;
    }
}
```

As you can see, the `Box()` constructor requires three parameters. This means that all declarations of `Box` objects must pass three arguments to the `Box()` constructor. For example, the following statement is currently invalid:

```java
Box ob = new Box();
```

Since `Box()` requires three arguments, it’s an error to call it without them. This raises some important questions. What if you simply wanted a box and did not care (or know) what its initial dimensions were? Or, what if you want to be able to initialize a cube by specifying only one value that would be used for all three dimensions? As the `Box` class is currently written, these other options are not
available to you.

Fortunately, the solution to these problems is quite easy: simply overload the **Box** constructor so that it handles the situations just described. Here is a program that contains an improved version of **Box** that does just that:
/ * Here, Box defines three constructors to initialize 
  the dimensions of a box various ways. 
 */

class Box {
    double width;
    double height;
    double depth;

    // constructor used when all dimensions specified
    Box(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }

    // constructor used when no dimensions specified
    Box() {
        width = -1; // use -1 to indicate
        height = -1; // an uninitialized
        depth = -1; // box
    }

    // constructor used when cube is created
    Box(double len) {
        width = height = depth = len;
    }

    // compute and return volume
    double volume() {
        return width * height * depth;
    }
}

class OverloadCons {
    public static void main(String[] args) {
        // create boxes using the various constructors
        Box mybox1 = new Box(10, 20, 15);
        Box mybox2 = new Box();
        Box mycube = new Box(7);

        double vol;

        // get volume of first box
        vol = mybox1.volume();
        System.out.println("Volume of mybox1 is " + vol);

        // get volume of second box
        vol = mybox2.volume();
        System.out.println("Volume of mybox2 is " + vol);

        // get volume of cube
        vol = mycube.volume();
        System.out.println("Volume of mycube is " + vol);
    }
}
The output produced by this program is shown here:

Volume of mybox1 is 3000.0
Volume of mybox2 is -1.0
Volume of mycube is 343.0

As you can see, the proper overloaded constructor is called based upon the arguments specified when `new` is executed.

### Using Objects as Parameters

So far, we have only been using simple types as parameters to methods. However, it is both correct and common to pass objects to methods. For example, consider the following short program:

```java
// Objects may be passed to methods.
class Test {
    int a, b;

    Test(int i, int j) {
        a = i;
        b = j;
    }

    // return true if o is equal to the invoking object
    boolean equalTo(Test o) {
        if(o.a == a && o.b == b) return true;
        else return false;
    }
}

class PassOb {
    public static void main(String args[]) {
        Test ob1 = new Test(100, 22);
        Test ob2 = new Test(100, 22);
        Test ob3 = new Test(-1, -1);

        System.out.println("ob1 == ob2: " + ob1.equalTo(ob2));
        System.out.println("ob1 == ob3: " + ob1.equalTo(ob3));
    }
}
```

This program generates the following output:
As you can see, the `equalTo( )` method inside `Test` compares two objects for equality and returns the result. That is, it compares the invoking object with the one that it is passed. If they contain the same values, then the method returns `true`. Otherwise, it returns `false`. Notice that the parameter `o` in `equalTo( )` specifies `Test` as its type. Although `Test` is a class type created by the program, it is used in just the same way as Java’s built-in types.

One of the most common uses of object parameters involves constructors. Frequently, you will want to construct a new object so that it is initially the same as some existing object. To do this, you must define a constructor that takes an object of its class as a parameter. For example, the following version of `Box` allows one object to initialize another:

```java
ob1 == ob2: true
ob1 == ob3: false
```
// Here, Box allows one object to initialize another.

class Box {
    double width;
    double height;
    double depth;

    // Notice this constructor. It takes an object of type Box.
    Box(Box ob) { // pass object to constructor
        width = ob.width;
        height = ob.height;
        depth = ob.depth;
    }

    // constructor used when all dimensions specified
    Box(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }

    // constructor used when no dimensions specified
    Box() {
        width = -1; // use -1 to indicate
        height = -1; // an uninitialized
        depth = -1; // box
    }

    // constructor used when cube is created
    Box(double len) {
        width = height = depth = len;
    }

    // compute and return volume
    double volume() {
        return width * height * depth;
    }
}

class OverloadCons2 {
    public static void main(String args[]) {
        // create boxes using the various constructors
        Box mybox1 = new Box(10, 20, 15);
        Box mybox2 = new Box();
        Box mycube = new Box(7);

        Box myclone = new Box(mybox1); // create copy of mybox1
        double vol;

        // get volume of first box
        vol = mybox1.volume();
        System.out.println("Volume of mybox1 is " + vol);

        // get volume of second box
        vol = mybox2.volume();
        System.out.println("Volume of mybox2 is " + vol);

        // get volume of cube
        vol = mycube.volume();
        System.out.println("Volume of cube is " + vol);

        // get volume of clone
        vol = myclone.volume();
        System.out.println("Volume of clone is " + vol);
    }
}
As you will see when you begin to create your own classes, providing many forms of constructors is usually required to allow objects to be constructed in a convenient and efficient manner.

A Closer Look at Argument Passing

In general, there are two ways that a computer language can pass an argument to a subroutine. The first way is call-by-value. This approach copies the value of an argument into the formal parameter of the subroutine. Therefore, changes made to the parameter of the subroutine have no effect on the argument. The second way an argument can be passed is call-by-reference. In this approach, a reference to an argument (not the value of the argument) is passed to the parameter. Inside the subroutine, this reference is used to access the actual argument specified in the call. This means that changes made to the parameter will affect the argument used to call the subroutine. As you will see, although Java uses call-by-value to pass all arguments, the precise effect differs between whether a primitive type or a reference type is passed.

When you pass a primitive type to a method, it is passed by value. Thus, a copy of the argument is made, and what occurs to the parameter that receives the argument has no effect outside the method. For example, consider the following program:
The output from this program is shown here:

```
// Primitive types are passed by value.
class Test {
    void meth(int i, int j) {
        i *= 2;
        j /= 2;
    }
}

class CallByValue {
    public static void main(String args[]) {
        Test ob = new Test();

        int a = 15, b = 20;

        System.out.println("a and b before call: " +
                        a + " " + b);

        ob.meth(a, b);

        System.out.println("a and b after call: " +
                        a + " " + b);
    }
}
```

As you can see, the operations that occur inside `meth()` have no effect on the values of `a` and `b` used in the call; their values here did not change to 30 and 10.

When you pass an object to a method, the situation changes dramatically, because objects are passed by what is effectively call-by-reference. Keep in mind that when you create a variable of a class type, you are only creating a reference to an object. Thus, when you pass this reference to a method, the parameter that receives it will refer to the same object as that referred to by the argument. This effectively means that objects act as if they are passed to methods by use of call-by-reference. Changes to the object inside the method do affect the object used as an argument. For example, consider the following program:
// Objects are passed through their references.

class Test {
    int a, b;

    Test(int i, int j) {
        a = i;
        b = j;
    }

    // pass an object
    void meth(Test o) {
        o.a *= 2;
        o.b /= 2;
    }
}

class PassObjRef {
    public static void main(String args[]) {
        Test ob = new Test(15, 20);
        System.out.println("ob.a and ob.b before call: "+
        ob.a + " " + ob.b);
        ob.meth(ob);
        System.out.println("ob.a and ob.b after call: "+
        ob.a + " " + ob.b);
    }
}

This program generates the following output:

ob.a and ob.b before call: 15 20
ob.a and ob.b after call: 30 10

As you can see, in this case, the actions inside `meth()` have affected the object used as an argument.

**REMEMBER** When an object reference is passed to a method, the reference itself is passed by use of call-by-value. However, since the value being passed refers to an object, the copy of that value will still refer to the same object that its corresponding argument does.
Returning Objects

A method can return any type of data, including class types that you create. For example, in the following program, the `incrByTen()` method returns an object in which the value of `a` is ten greater than it is in the invoking object.

```java
// Returning an object.
class Test {
    int a;

    Test(int i) {
        a = i;
    }

    Test incrByTen() {
        Test temp = new Test(a+10);
        return temp;
    }
}

class RetOb {
    public static void main(String args[]) {
        Test ob1 = new Test(2);
        Test ob2;

        ob2 = ob1.incrByTen();
        System.out.println("ob1.a: "+ ob1.a);
        System.out.println("ob2.a: "+ ob2.a);
        ob2 = ob2.incrByTen();
        System.out.println("ob2.a after second increase: "+ ob2.a);
    }
}
```

The output generated by this program is shown here:

```
ob1.a: 2
ob2.a: 12
ob2.a after second increase: 22
```

As you can see, each time `incrByTen()` is invoked, a new object is created, and a reference to it is returned to the calling routine.

The preceding program makes another important point: Since all objects are dynamically allocated using `new`, you don’t need to worry about an object going out-
of-scope because the method in which it was created terminates. The object will continue to exist as long as there is a reference to it somewhere in your program. When there are no references to it, the object will be reclaimed the next time garbage collection takes place.

Recursion

Java supports recursion. Recursion is the process of defining something in terms of itself. As it relates to Java programming, recursion is the attribute that allows a method to call itself. A method that calls itself is said to be recursive.

The classic example of recursion is the computation of the factorial of a number. The factorial of a number \( N \) is the product of all the whole numbers between 1 and \( N \). For example, 3 factorial is \( 1 \times 2 \times 3 \times \), or 6. Here is how a factorial can be computed by use of a recursive method:

```java
// A simple example of recursion.
class Factorial {
    // this is a recursive method
    int fact(int n) {
        int result;

        if(n==1) return 1;
        result = fact(n-1) * n;
        return result;
    }
}

class Recursion {
    public static void main(String args[]) {
        Factorial f = new Factorial();

        System.out.println("Factorial of 3 is " + f.fact(3));
        System.out.println("Factorial of 4 is " + f.fact(4));
        System.out.println("Factorial of 5 is " + f.fact(5));
    }
}
```

The output from this program is shown here:

```
Factorial of 3 is 6
Factorial of 4 is 24
Factorial of 5 is 120
```
If you are unfamiliar with recursive methods, then the operation of \texttt{fact()} may seem a bit confusing. Here is how it works. When \texttt{fact()} is called with an argument of 1, the function returns 1; otherwise, it returns the product of \texttt{fact(n–1)\times n}. To evaluate this expression, \texttt{fact()} is called with \texttt{n–1}. This process repeats until \texttt{n} equals 1 and the calls to the method begin returning.

To better understand how the \texttt{fact()} method works, let’s go through a short example. When you compute the factorial of 3, the first call to \texttt{fact()} will cause a second call to be made with an argument of 2. This invocation will cause \texttt{fact()} to be called a third time with an argument of 1. This call will return 1, which is then multiplied by 2 (the value of \texttt{n} in the second invocation). This result (which is 2) is then returned to the original invocation of \texttt{fact()} and multiplied by 3 (the original value of \texttt{n}). This yields the answer, 6. You might find it interesting to insert \texttt{println()} statements into \texttt{fact()}, which will show at what level each call is and what the intermediate answers are.

When a method calls itself, new local variables and parameters are allocated storage on the stack, and the method code is executed with these new variables from the start. As each recursive call returns, the old local variables and parameters are removed from the stack, and execution resumes at the point of the call inside the method. Recursive methods could be said to “telescope” out and back.

Recursive versions of many routines may execute a bit more slowly than the iterative equivalent because of the added overhead of the additional method calls. A large number of recursive calls to a method could cause a stack overrun. Because storage for parameters and local variables is on the stack and each new call creates a new copy of these variables, it is possible that the stack could be exhausted. If this occurs, the Java run-time system will cause an exception. However, this is typically not an issue unless a recursive routine runs wild.

The main advantage to recursive methods is that they can be used to create clearer and simpler versions of several algorithms than can their iterative relatives. For example, the QuickSort sorting algorithm is quite difficult to implement in an iterative way. Also, some types of AI-related algorithms are most easily implemented using recursive solutions.

When writing recursive methods, you must have an \texttt{if} statement somewhere to force the method to return without the recursive call being executed. If you don’t do this, once you call the method, it will never return. This is a very common error in working with recursion. Use \texttt{println()} statements liberally during development so that you can watch what is going on and abort execution if you see that you have made a mistake.

Here is one more example of recursion. The recursive method \texttt{printArray()} prints the first \texttt{i} elements in the array \texttt{values}. 
This program generates the following output:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>[0]</td>
<td>0</td>
</tr>
<tr>
<td>[1]</td>
<td>1</td>
</tr>
<tr>
<td>[2]</td>
<td>2</td>
</tr>
<tr>
<td>[3]</td>
<td>3</td>
</tr>
<tr>
<td>[4]</td>
<td>4</td>
</tr>
<tr>
<td>[5]</td>
<td>5</td>
</tr>
<tr>
<td>[6]</td>
<td>6</td>
</tr>
<tr>
<td>[7]</td>
<td>7</td>
</tr>
<tr>
<td>[8]</td>
<td>8</td>
</tr>
<tr>
<td>[9]</td>
<td>9</td>
</tr>
</tbody>
</table>

**Introducing Access Control**

As you know, encapsulation links data with the code that manipulates it. However, encapsulation provides another important attribute: access control. Through
encapsulation, you can control what parts of a program can access the members of a
class. By controlling access, you can prevent misuse. For example, allowing access
to data only through a well-defined set of methods, you can prevent the misuse of
that data. Thus, when correctly implemented, a class creates a “black box” which
may be used, but the inner workings of which are not open to tampering. However,
the classes that were presented earlier do not completely meet this goal. For
example, consider the **Stack** class shown at the end of **Chapter 6**. While it is true that
the methods **push( )** and **pop( )** do provide a controlled interface to the stack, this
interface is not enforced. That is, it is possible for another part of the program to
bypass these methods and access the stack directly. Of course, in the wrong hands,
this could lead to trouble. In this section, you will be introduced to the mechanism by
which you can precisely control access to the various members of a class.

How a member can be accessed is determined by the **access modifier** attached to
its declaration. Java supplies a rich set of access modifiers. Some aspects of access
control are related mostly to inheritance or packages. (A **package** is, essentially, a
grouping of classes.) These parts of Java’s access control mechanism will be
discussed in subsequent chapters. Here, let’s begin by examining access control as it
applies to a single class. Once you understand the fundamentals of access control,
the rest will be easy.

**NOTE** The new modules feature added by JDK 9 can also impact accessibility.
      Modules are described in **Chapter 16**.

Java’s access modifiers are **public**, **private**, and **protected**. Java also defines a
default access level. **protected** applies only when inheritance is involved. The other
access modifiers are described next.

Let’s begin by defining **public** and **private**. When a member of a class is
modified by **public**, then that member can be accessed by any other code. When a
member of a class is specified as **private**, then that member can only be accessed by
other members of its class. Now you can understand why **main( )** has always been
preceded by the **public** modifier. It is called by code that is outside the program—
that is, by the Java run-time system. When no access modifier is used, then by
default the member of a class is public within its own package, but cannot be
accessed outside of its package. (Packages are discussed in **Chapter 9**.)

In the classes developed so far, all members of a class have used the default
access mode. However, this is not what you will typically want to be the case.
Usually, you will want to restrict access to the data members of a class—allowing
access only through methods. Also, there will be times when you will want to define
methods that are private to a class.

An access modifier precedes the rest of a member’s type specification. That is, it
must begin a member’s declaration statement. Here is an example:

    public int i;
    private double j;

    private int myMethod(int a, char b) { // ...

    To understand the effects of public and private access, consider the following program:

    /* This program demonstrates the difference between
       public and private.
    */
    class Test {
        int a; // default access
        public int b; // public access
        private int c; // private access

        // methods to access c
        void setc(int i) { // set c's value
            c = i;
        }
        int getc() { // get c's value
            return c;
        }
    }
    class AccessTest {
        public static void main(String args[]) {
            Test ob = new Test();

            // These are OK, a and b may be accessed directly
            ob.a = 10;
            ob.b = 20;

            // This is not OK and will cause an error
            // ob.c = 100; // Error!

            // You must access c through its methods
            ob.setc(100); // OK
            System.out.println("a, b, and c: "+ob.a+" "+
                            ob.b+" "+ob.getc());
        }
    }
As you can see, inside the Test class, a uses default access, which for this example is the same as specifying public. b is explicitly specified as public. Member c is given private access. This means that it cannot be accessed by code outside of its class. So, inside the AccessTest class, c cannot be used directly. It must be accessed through its public methods: setc() and getc(). If you were to remove the comment symbol from the beginning of the following line,

```java
// ob.c = 100; // Error!
```

then you would not be able to compile this program because of the access violation.

To see how access control can be applied to a more practical example, consider the following improved version of the Stack class shown at the end of Chapter 6.

```java
// This class defines an integer stack that can hold 10 values.
class Stack {
    /* Now, both stck and tos are private. This means
        that they cannot be accidentally or maliciously
        altered in a way that would be harmful to the stack.
    */
    private int stck[] = new int[10];
    private int tos;

    // Initialize top-of-stack
    Stack() {
        tos = -1;
    }

    // Push an item onto the stack
    void push(int item) {
        if(tos==9)
            System.out.println("Stack is full.");
        else
            stck[++tos] = item;
    }
```
As you can see, now both stck, which holds the stack, and tos, which is the index of the top of the stack, are specified as private. This means that they cannot be accessed or altered except through push( ) and pop( ). Making tos private, for example, prevents other parts of your program from inadvertently setting it to a value that is beyond the end of the stck array.

The following program demonstrates the improved Stack class. Try removing the commented-out lines to prove to yourself that the stck and tos members are, indeed, inaccessible.
Although methods will usually provide access to the data defined by a class, this does not always have to be the case. It is perfectly proper to allow an instance variable to be public when there is good reason to do so. For example, most of the simple classes in this book were created with little concern about controlling access to instance variables for the sake of simplicity. However, in most real-world classes, you will need to allow operations on data only through methods. The next chapter will return to the topic of access control. As you will see, it is particularly important when inheritance is involved.

**Understanding static**

There will be times when you will want to define a class member that will be used independently of any object of that class. Normally, a class member must be accessed only in conjunction with an object of its class. However, it is possible to create a member that can be used by itself, without reference to a specific instance. To create such a member, precede its declaration with the keyword `static`. When a member is declared `static`, it can be accessed before any objects of its class are

```java
class TestStack {
    public static void main(String args[]) {
        Stack mystack1 = new Stack();
        Stack mystack2 = new Stack();

        // push some numbers onto the stack
        for(int i=0; i<10; i++) mystack1.push(i);
        for(int i=10; i<20; i++) mystack2.push(i);

        // pop those numbers off the stack
        System.out.println("Stack in mystack1:");
        for(int i=0; i<10; i++)
            System.out.println(mystack1.pop());
        System.out.println("Stack in mystack2:");
        for(int i=0; i<10; i++)
            System.out.println(mystack2.pop());

        // these statements are not legal
        // mystack1.tos = -2;
        // mystack2.stck[3] = 100;
    }
}
```
created, and without reference to any object. You can declare both methods and variables to be static. The most common example of a static member is main(). main( ) is declared as static because it must be called before any objects exist.

Instance variables declared as static are, essentially, global variables. When objects of its class are declared, no copy of a static variable is made. Instead, all instances of the class share the same static variable.

Methods declared as static have several restrictions:

- They can only directly call other static methods of their class.
- They can only directly access static variables of their class.
- They cannot refer to this or super in any way. (The keyword super relates to inheritance and is described in the next chapter.)

If you need to do computation in order to initialize your static variables, you can declare a static block that gets executed exactly once, when the class is first loaded. The following example shows a class that has a static method, some static variables, and a static initialization block:

```java
// Demonstrate static variables, methods, and blocks.
class UseStatic {
    static int a = 3;
    static int b;

    static void meth(int x) {
        System.out.println("x = " + x);
        System.out.println("a = " + a);
        System.out.println("b = " + b);
    }

    static {
        System.out.println("Static block initialized.");
        b = a * 4;
    }

    public static void main(String args[]) {  
        meth(42);
    }
}
```

As soon as the UseStatic class is loaded, all of the static statements are run. First, a is set to 3, then the static block executes, which prints a message and then initializes b to a*4 or 12. Then main( ) is called, which calls meth( ), passing 42 to
x. The three `println()` statements refer to the two static variables a and b, as well as to the parameter x.

Here is the output of the program:

```
Static block initialized.
x = 42
a = 3
b = 12
```

Outside of the class in which they are defined, static methods and variables can be used independently of any object. To do so, you need only specify the name of their class followed by the dot operator. For example, if you wish to call a static method from outside its class, you can do so using the following general form:

```
classname.method()
```

Here, `classname` is the name of the class in which the static method is declared. As you can see, this format is similar to that used to call non-static methods through object-reference variables. A static variable can be accessed in the same way—by use of the dot operator on the name of the class. This is how Java implements a controlled version of global methods and global variables.

Here is an example. Inside `main()`, the static method `callme()` and the static variable `b` are accessed through their class name `StaticDemo`.

```java
class StaticDemo {
    static int a = 42;
    static int b = 99;

    static void callme() {
        System.out.println("a = " + a);
    }
}

class StaticByName {
    public static void main(String args[]) {
        StaticDemo.callme();
        System.out.println("b = " + StaticDemo.b);
    }
}
```

Here is the output of this program:

```
a = 42
b = 99
```
Introducing final

A field can be declared as final. Doing so prevents its contents from being modified, making it, essentially, a constant. This means that you must initialize a final field when it is declared. You can do this in one of two ways: First, you can give it a value when it is declared. Second, you can assign it a value within a constructor. The first approach is the most common. Here is an example:

```java
final int FILE_NEW = 1;
final int FILE_OPEN = 2;
final int FILE_SAVE = 3;
final int FILE_SAVEAS = 4;
final int FILE_QUIT = 5;
```

Subsequent parts of your program can now use FILE_OPEN, etc., as if they were constants, without fear that a value has been changed. It is a common coding convention to choose all uppercase identifiers for final fields, as this example shows.

In addition to fields, both method parameters and local variables can be declared final. Declaring a parameter final prevents it from being changed within the method. Declaring a local variable final prevents it from being assigned a value more than once.

The keyword final can also be applied to methods, but its meaning is substantially different than when it is applied to variables. This additional usage of final is described in the next chapter, when inheritance is described.

Arrays Revisited

Arrays were introduced earlier in this book, before classes had been discussed. Now that you know about classes, an important point can be made about arrays: they are implemented as objects. Because of this, there is a special array attribute that you will want to take advantage of. Specifically, the size of an array—that is, the number of elements that an array can hold—is found in its length instance variable. All arrays have this variable, and it will always hold the size of the array. Here is a program that demonstrates this property:
This program displays the following output:

length of a1 is 10
length of a2 is 8
length of a3 is 4

As you can see, the size of each array is displayed. Keep in mind that the value of \texttt{length} has nothing to do with the number of elements that are actually in use. It only reflects the number of elements that the array is designed to hold.

You can put the \texttt{length} member to good use in many situations. For example, here is an improved version of the \texttt{Stack} class. As you might recall, the earlier versions of this class always created a ten-element stack. The following version lets you create stacks of any size. The value of \texttt{stck.length} is used to prevent the stack from overflowing.
// Improved Stack class that uses the length array member.
class Stack {
    private int stck[];
    private int tos;

    // allocate and initialize stack
    Stack(int size) {
        stck = new int[size];
        tos = -1;
    }

    // Push an item onto the stack
    void push(int item) {
        if(tos==stck.length-1) // use length member
            System.out.println("Stack is full.");
        else
            stck[++tos] = item;
    }

    // Pop an item from the stack
    int pop() {
        if(tos < 0) {
            System.out.println("Stack underflow.");
            return 0;
        }
        else
            return stck[tos--];
    }
}

class TestStack2 {
    public static void main(String args[]) {
        Stack mystack1 = new Stack(5);
        Stack mystack2 = new Stack(8);

        // push some numbers onto the stack
        for(int i=0; i<5; i++) mystack1.push(i);
        for(int i=0; i<8; i++) mystack2.push(i);

        // pop those numbers off the stack
        System.out.println("Stack in mystack1:");
        for(int i=0; i<5; i++)
            System.out.println(mystack1.pop());

        System.out.println("Stack in mystack2:");
        for(int i=0; i<8; i++)
            System.out.println(mystack2.pop());
    }
}
Notice that the program creates two stacks: one five elements deep and the other eight elements deep. As you can see, the fact that arrays maintain their own length information makes it easy to create stacks of any size.

**Introducing Nested and Inner Classes**

It is possible to define a class within another class; such classes are known as *nested classes*. The scope of a nested class is bounded by the scope of its enclosing class. Thus, if class B is defined within class A, then B does not exist independently of A. A nested class has access to the members, including private members, of the class in which it is nested. However, the enclosing class does not have access to the members of the nested class. A nested class that is declared directly within its enclosing class scope is a member of its enclosing class. It is also possible to declare a nested class that is local to a block.

There are two types of nested classes: *static* and *non-static*. A static nested class is one that has the *static* modifier applied. Because it is static, it must access the non-static members of its enclosing class through an object. That is, it cannot refer to non-static members of its enclosing class directly. Because of this restriction, static nested classes are seldom used.

The most important type of nested class is the *inner* class. An inner class is a non-static nested class. It has access to all of the variables and methods of its outer class and may refer to them directly in the same way that other non-static members of the outer class do.

The following program illustrates how to define and use an inner class. The class named **Outer** has one instance variable named **outer_x**, one instance method named **test()**, and defines one inner class called **Inner**.
// Demonstrate an inner class.
class Outer {
    int outer_x = 100;

    void test() {
        Inner inner = new Inner();
        inner.display();
    }
}

// this is an inner class
class Inner {
    void display() {
        System.out.println("display: outer_x = " + outer_x);
    }
}

class InnerClassDemo {
    public static void main(String args[]) {
        Outer outer = new Outer();
        outer.test();
    }
}

Output from this application is shown here:

display: outer_x = 100

In the program, an inner class named Inner is defined within the scope of class Outer. Therefore, any code in class Inner can directly access the variable outer_x. An instance method named display() is defined inside Inner. This method displays outer_x on the standard output stream. The main() method of InnerClassDemo creates an instance of class Outer and invokes its test() method. That method creates an instance of class Inner and the display() method is called.

It is important to realize that an instance of Inner can be created only in the context of class Outer. The Java compiler generates an error message otherwise. In general, an inner class instance is often created by code within its enclosing scope, as the example does.

As explained, an inner class has access to all of the members of its enclosing class, but the reverse is not true. Members of the inner class are known only within the scope of the inner class and may not be used by the outer class. For example,
Here, \( y \) is declared as an instance variable of \texttt{Inner}. Thus, it is not known outside of that class and it cannot be used by \texttt{showy()}. 

Although we have been focusing on inner classes declared as members within an outer class scope, it is possible to define inner classes within any block scope. For example, you can define a nested class within the block defined by a method or even within the body of a \texttt{for} loop, as this next program shows:

```java
// This program will not compile.
class Outer {
    int outer_x = 100;

    void test() {
        Inner inner = new Inner();
        inner.display();
    }

    // this is an inner class
    class Inner {
        int y = 10; // y is local to Inner

        void display() {
            System.out.println("display: outer_x = " + outer_x);
        }
    }

    void showy() {
        System.out.println(y);  // error, y not known here!
    }
}

class InnerClassDemo {
    public static void main(String args[]) {
        Outer outer = new Outer();
        outer.test();
    }
}
```

Here, \( y \) is declared as an instance variable of \texttt{Inner}. Thus, it is not known outside of that class and it cannot be used by \texttt{showy()}. 

Although we have been focusing on inner classes declared as members within an outer class scope, it is possible to define inner classes within any block scope. For example, you can define a nested class within the block defined by a method or even within the body of a \texttt{for} loop, as this next program shows:
The output from this version of the program is shown here:

display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100

display: outer_x = 100

display: outer_x = 100

display: outer_x = 100

display: outer_x = 100

display: outer_x = 100

display: outer_x = 100

While nested classes are not applicable to all situations, they are particularly helpful when handling events. We will return to the topic of nested classes in Chapter 24. There you will see how inner classes can be used to simplify the code needed to handle certain types of events. You will also learn about anonymous inner classes, which are inner classes that don’t have a name.

One point of interest: Nested classes were not allowed by the original 1.0 specification for Java. They were added by Java 1.1.
Exploring the String Class

Although the **String** class will be examined in depth in **Part II** of this book, a short exploration of it is warranted now, because we will be using strings in some of the example programs shown toward the end of **Part I**. **String** is probably the most commonly used class in Java’s class library. The obvious reason for this is that strings are a very important part of programming.

The first thing to understand about strings is that every string you create is actually an object of type **String**. Even string constants are actually **String** objects. For example, in the statement

```java
System.out.println("This is a String, too");
```

the string "This is a String, too" is a **String** object.

The second thing to understand about strings is that objects of type **String** are immutable; once a **String** object is created, its contents cannot be altered. While this may seem like a serious restriction, it is not, for two reasons:

- If you need to change a string, you can always create a new one that contains the modifications.
- Java defines peer classes of **String**, called **StringBuilder** and **StringBuffer**, which allow strings to be altered, so all of the normal string manipulations are still available in Java. (**StringBuilder** and **StringBuffer** are described in **Part II** of this book.)

Strings can be constructed in a variety of ways. The easiest is to use a statement like this:

```java
String myString = "this is a test";
```

Once you have created a **String** object, you can use it anywhere that a string is allowed. For example, this statement displays **myString**:

```java
System.out.println(myString);
```

Java defines one operator for **String** objects: +. It is used to concatenate two strings. For example, this statement

```java
String myString = "I" + " like " + "Java.";
```

results in **myString** containing "I like Java."

The following program demonstrates the preceding concepts:
The output produced by this program is shown here:

First String
Second String
First String and Second String

The String class contains several methods that you can use. Here are a few. You can test two strings for equality by using equals(). You can obtain the length of a string by calling the length() method. You can obtain the character at a specified index within a string by calling charAt(). The general forms of these three methods are shown here:

    boolean equals(secondStr)
    int length()
    char charAt(index)

Here is a program that demonstrates these methods:
This program generates the following output:

Length of strOb1: 12
Char at index 3 in strOb1: s
strOb1 != strOb2
strOb1 == strOb3

Of course, you can have arrays of strings, just like you can have arrays of any other type of object. For example:
Here is the output from this program:

```
str[0]: one
str[1]: two
str[2]: three
```

As you will see in the following section, string arrays play an important part in many Java programs.

**Using Command-Line Arguments**

Sometimes you will want to pass information into a program when you run it. This is accomplished by passing command-line arguments to `main()`. A command-line argument is the information that directly follows the program’s name on the command line when it is executed. To access the command-line arguments inside a Java program is quite easy—they are stored as strings in a `String` array passed to the `args` parameter of `main()`. The first command-line argument is stored at `args[0]`, the second at `args[1]`, and so on. For example, the following program displays all of the command-line arguments that it is called with:

```java
// Display all command-line arguments.
class CommandLine {
    public static void main(String args[]) {
        for(int i=0; i<args.length; i++)
            System.out.println("args[" + i + "]: " +
                                      args[i]);
    }
}
```
Try executing this program, as shown here:

testCommandLine this is a test 100 -1

When you do, you will see the following output:

```
args[0]: this
args[1]: is
args[2]: a
args[3]: test
args[4]: 100
args[5]: -1
```

*REMEMBER* All command-line arguments are passed as strings. You must convert numeric values to their internal forms manually, as explained in Chapter 18.

### Varargs: Variable-Length Arguments

Beginning with JDK 5, Java has included a feature that simplifies the creation of methods that need to take a variable number of arguments. This feature is called *varargs* and it is short for *variable-length arguments*. A method that takes a variable number of arguments is called a *variable-arity method*, or simply a *varargs method*.

Situations that require that a variable number of arguments be passed to a method are not unusual. For example, a method that opens an Internet connection might take a user name, password, filename, protocol, and so on, but supply defaults if some of this information is not provided. In this situation, it would be convenient to pass only the arguments to which the defaults did not apply. Another example is the `printf()` method that is part of Java’s I/O library. As you will see in Chapter 21, it takes a variable number of arguments, which it formats and then outputs.

Prior to JDK 5, variable-length arguments could be handled two ways, neither of which was particularly pleasing. First, if the maximum number of arguments was small and known, then you could create overloaded versions of the method, one for each way the method could be called. Although this works and is suitable for some cases, it applies to only a narrow class of situations.

In cases where the maximum number of potential arguments was larger, or unknowable, a second approach was used in which the arguments were put into an array, and then the array was passed to the method. This approach is illustrated by the following program:
The output from the program is shown here:

Number of args: 1 Contents: 10
Number of args: 3 Contents: 1 2 3
Number of args: 0 Contents:

In the program, the method `vaTest()` is passed its arguments through the array `v`. This old-style approach to variable-length arguments does enable `vaTest()` to take an arbitrary number of arguments. However, it requires that these arguments be manually packaged into an array prior to calling `vaTest()`. Not only is it tedious to construct an array each time `vaTest()` is called, it is potentially error-prone. The varargs feature offers a simpler, better option.

A variable-length argument is specified by three periods (`...`). For example, here is how `vaTest()` is written using a vararg:

```
static void vaTest(int ... v) {
```
This syntax tells the compiler that `vaTest()` can be called with zero or more arguments. As a result, `v` is implicitly declared as an array of type `int[]`. Thus, inside `vaTest()`, `v` is accessed using the normal array syntax. Here is the preceding program rewritten using a vararg:

```java
// Demonstrate variable-length arguments.
class VarArgs {

    // vaTest() now uses a vararg.
    static void vaTest(int ... v) {
        System.out.print("Number of args: ", v.length + " Contents: ");

        for(int x : v)
            System.out.print(x + " ");

        System.out.println();
    }

    public static void main(String args[])
    {
        // Notice how vaTest() can be called with a
        // variable number of arguments.
        vaTest(10);       // 1 arg
        vaTest(1, 2, 3);  // 3 args
        vaTest();         // no args
    }
}
```

The output from the program is the same as the original version.

There are two important things to notice about this program. First, as explained, inside `vaTest()`, `v` is operated on as an array. This is because `v` is an array. The `...` syntax simply tells the compiler that a variable number of arguments will be used, and that these arguments will be stored in the array referred to by `v`. Second, in `main()`, `vaTest()` is called with different numbers of arguments, including no arguments at all. The arguments are automatically put in an array and passed to `v`. In the case of no arguments, the length of the array is zero.

A method can have "normal" parameters along with a variable-length parameter. However, the variable-length parameter must be the last parameter declared by the method. For example, this method declaration is perfectly acceptable:

```java
int doit(int a, int b, double c, int ... vals) {
```
In this case, the first three arguments used in a call to `doIt()` are matched to the first three parameters. Then, any remaining arguments are assumed to belong to `vals`.

Remember, the varargs parameter must be last. For example, the following declaration is incorrect:

```java
int doIt(int a, int b, double c, int ... vals, boolean stopFlag) { // Error!
```

Here, there is an attempt to declare a regular parameter after the varargs parameter, which is illegal.

There is one more restriction to be aware of: there must be only one varargs parameter. For example, this declaration is also invalid:

```java
int doIt(int a, int b, double c, int ... vals, double ... morevals) { // Error!
```

The attempt to declare the second varargs parameter is illegal.

Here is a reworked version of the `vaTest()` method that takes a regular argument and a variable-length argument:

```java
// Use varargs with standard arguments.
class VarArgs2 {

    // Here, msg is a normal parameter and v is a // varargs parameter.
    static void vaTest(String msg, int ... v) {
        System.out.print(msg + v.length +
                        " Contents: ");

        for(int x : v)
            System.out.print(x + " ");

        System.out.println();
    }

    public static void main(String args[]) {
        vaTest("One vararg: ", 10);
        vaTest("Three varargs: ", 1, 2, 3);
        vaTest("No varargs: ");
    }
}
```

The output from this program is shown here:
Overloading Vararg Methods

You can overload a method that takes a variable-length argument. For example, the following program overloads `vaTest()` three times:
// Varargs and overloading.
class VarArgs3 {

    static void vaTest(int ... v) {
        System.out.print("vaTest(int ...): " +
                         "Number of args: " + v.length +
                         " Contents: ");

        for(int x : v)
            System.out.print(x + " ");

        System.out.println();
    }

    static void vaTest(boolean ... v) {
        System.out.print("vaTest(boolean ...) " +
                          "Number of args: " + v.length +
                          " Contents: ");

        for(boolean x : v)
            System.out.print(x + " ");

        System.out.println();
    }

    static void vaTest(String msg, int ... v) {
        System.out.print("vaTest(String, int ...)": " +
                         msg + v.length +
                         " Contents: ");

        for(int x : v)
            System.out.print(x + " ");

        System.out.println();
    }

    public static void main(String args[])
    {
        vaTest(1, 2, 3);
        vaTest("Testing: ", 10, 20);
        vaTest(true, false, false);
    }
}
The output produced by this program is shown here:

vaTest(int ...): Number of args: 3 Contents: 1 2 3
vaTest(String, int ...): Testing: 2 Contents: 10 20
vaTest(boolean ...) Number of args: 3 Contents: true false false

This program illustrates both ways that a varargs method can be overloaded. First, the types of its vararg parameter can differ. This is the case for `vaTest(int ...)` and `vaTest(boolean ...`). Remember, the `...` causes the parameter to be treated as an array of the specified type. Therefore, just as you can overload methods by using different types of array parameters, you can overload vararg methods by using different types of varargs. In this case, Java uses the type difference to determine which overloaded method to call.

The second way to overload a varargs method is to add one or more normal parameters. This is what was done with `vaTest(String, int ...)`. In this case, Java uses both the number of arguments and the type of the arguments to determine which method to call.

**NOTE** A varargs method can also be overloaded by a non-varargs method. For example, `vaTest(int x)` is a valid overload of `vaTest()` in the foregoing program. This version is invoked only when one `int` argument is present. When two or more `int` arguments are passed, the varargs version `vaTest(int...v)` is used.

**Varargs and Ambiguity**

Somewhat unexpected errors can result when overloading a method that takes a variable-length argument. These errors involve ambiguity because it is possible to create an ambiguous call to an overloaded varargs method. For example, consider the following program:
In this program, the overloading of `vaTest()` is perfectly correct. However, this program will not compile because of the following call:

```java
vaTest(); // Error: Ambiguous!
```

Because the vararg parameter can be empty, this call could be translated into a call to `vaTest(int ...)` or `vaTest(boolean ...)`. Both are equally valid. Thus, the call is inherently ambiguous.
Here is another example of ambiguity. The following overloaded versions of `vaTest()` are inherently ambiguous even though one takes a normal parameter:

```java
static void vaTest(int ... v) { // ...
static void vaTest(int n, int ... v) { // ...
```

Although the parameter lists of `vaTest()` differ, there is no way for the compiler to resolve the following call:

```java
vaTest(1)
```

Does this translate into a call to `vaTest(int ...)`, with one varargs argument, or into a call to `vaTest(int, int ...)`, with no varargs arguments? There is no way for the compiler to answer this question. Thus, the situation is ambiguous.

Because of ambiguity errors like those just shown, sometimes you will need to forego overloading and simply use two different method names. Also, in some cases, ambiguity errors expose a conceptual flaw in your code, which you can remedy by more carefully crafting a solution.
Inheritance

Inheritance is one of the cornerstones of object-oriented programming because it allows the creation of hierarchical classifications. Using inheritance, you can create a general class that defines traits common to a set of related items. This class can then be inherited by other, more specific classes, each adding those things that are unique to it. In the terminology of Java, a class that is inherited is called a superclass. The class that does the inheriting is called a subclass. Therefore, a subclass is a specialized version of a superclass. It inherits all of the members defined by the superclass and adds its own, unique elements.

Inheritance Basics

To inherit a class, you simply incorporate the definition of one class into another by using the **extends** keyword. To see how, let’s begin with a short example. The following program creates a superclass called **A** and a subclass called **B**. Notice how the keyword **extends** is used to create a subclass of **A**.
// A simple example of inheritance.

// Create a superclass.
class A {
    int i, j;

    void showij() {
        System.out.println("i and j: " + i + " " + j);
    }
}

// Create a subclass by extending class A.
class B extends A {
    int k;

    void showk() {
        System.out.println("k: " + k);
    }

    void sum() {
        System.out.println("i+j+k: " + (i+j+k));
    }
}
class SimpleInheritance {
    public static void main(String args []) {
        A superOb = new A();
        B subOb = new B();

        // The superclass may be used by itself.
        superOb.i = 10;
        superOb.j = 20;
        System.out.println("Contents of superOb: ");
        superOb.showij();
        System.out.println();

        /* The subclass has access to all public members of its superclass. */
        subOb.i = 7;
        subOb.j = 8;
        subOb.k = 9;
        System.out.println("Contents of subOb: ");
        subOb.showij();
        subOb.showk();
        System.out.println();

        System.out.println("Sum of i, j and k in subOb: ");
        subOb.sum();
    }
}

The output from this program is shown here:

Contents of superOb:
i and j: 10 20

Contents of subOb:
i and j: 7 8
k: 9

Sum of i, j and k in subOb:
i+j+k: 24

As you can see, the subclass B includes all of the members of its superclass, A. This is why subOb can access i and j and call showij(). Also, inside sum(), i and j can be referred to directly, as if they were part of B.

Even though A is a superclass for B, it is also a completely independent, stand-alone class. Being a superclass for a subclass does not mean that the superclass
cannot be used by itself. Further, a subclass can be a superclass for another subclass.

The general form of a class declaration that inherits a superclass is shown here:

```java
class subclass-name extends superclass-name {
    // body of class
}
```

You can only specify one superclass for any subclass that you create. Java does not support the inheritance of multiple superclasses into a single subclass. You can, as stated, create a hierarchy of inheritance in which a subclass becomes a superclass of another subclass. However, no class can be a superclass of itself.

**Member Access and Inheritance**

Although a subclass includes all of the members of its superclass, it cannot access those members of the superclass that have been declared as **private**. For example, consider the following simple class hierarchy:
This program will not compile because the use of j inside the sum( ) method of B causes an access violation. Since j is declared as private, it is only accessible by other members of its own class. Subclasses have no access to it.

REMEMBER A class member that has been declared as private will remain private to its class. It is not accessible by any code outside its class, including
subclasses.

**A More Practical Example**

Let’s look at a more practical example that will help illustrate the power of inheritance. Here, the final version of the **Box** class developed in the preceding chapter will be extended to include a fourth component called **weight**. Thus, the new class will contain a box’s width, height, depth, and weight.

```java
// This program uses inheritance to extend Box.
class Box {
    double width;
    double height;
    double depth;

    // construct clone of an object
    Box(Box ob) { // pass object to constructor
        width = ob.width;
        height = ob.height;
        depth = ob.depth;
    }

    // constructor used when all dimensions specified
    Box(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }

    // constructor used when no dimensions specified
    Box() {
        width = -1; // use -1 to indicate
        height = -1; // an uninitialized
        depth = -1; // box
    }
```
// constructor used when cube is created
Box(double len) {
    width = height = depth = len;
}

// compute and return volume
double volume() {
    return width * height * depth;
}

// Here, Box is extended to include weight.
class BoxWeight extends Box {
    double weight; // weight of box

    // constructor for BoxWeight
    BoxWeight(double w, double h, double d, double m) {
        width = w;
        height = h;
        depth = d;
        weight = m;
    }
}

class DemoBoxWeight {
    public static void main(String args[]) {
        BoxWeight mybox1 = new BoxWeight(10, 20, 15, 34.3);
        BoxWeight mybox2 = new BoxWeight(2, 3, 4, 0.076);
        double vol;

        vol = mybox1.volume();
        System.out.println("Volume of mybox1 is "+ vol);
        System.out.println("Weight of mybox1 is " + mybox1.weight);
        System.out.println();

        vol = mybox2.volume();
        System.out.println("Volume of mybox2 is "+ vol);
        System.out.println("Weight of mybox2 is " + mybox2.weight);
    }
}

The output from this program is shown here:
BoxWeight inherits all of the characteristics of Box and adds to them the weight component. It is not necessary for BoxWeight to re-create all of the features found in Box. It can simply extend Box to meet its own purposes.

A major advantage of inheritance is that once you have created a superclass that defines the attributes common to a set of objects, it can be used to create any number of more specific subclasses. Each subclass can precisely tailor its own classification. For example, the following class inherits Box and adds a color attribute:

```java
// Here, Box is extended to include color.
class ColorBox extends Box {
    int color; // color of box

    ColorBox(double w, double h, double d, int c) {
        width = w;
        height = h;
        depth = d;
        color = c;
    }
}
```

Remember, once you have created a superclass that defines the general aspects of an object, that superclass can be inherited to form specialized classes. Each subclass simply adds its own unique attributes. This is the essence of inheritance.

**A Superclass Variable Can Reference a Subclass Object**

A reference variable of a superclass can be assigned a reference to any subclass derived from that superclass. You will find this aspect of inheritance quite useful in a variety of situations. For example, consider the following:

```java
Volume of mybox1 is 3000.0
Weight of mybox1 is 34.3

Volume of mybox2 is 24.0
Weight of mybox2 is 0.076
```
Here, `weightbox` is a reference to `BoxWeight` objects, and `plainbox` is a reference to `Box` objects. Since `BoxWeight` is a subclass of `Box`, it is permissible to assign `plainbox` a reference to the `weightbox` object.

It is important to understand that it is the type of the reference variable—not the type of the object that it refers to—that determines what members can be accessed. That is, when a reference to a subclass object is assigned to a superclass reference variable, you will have access only to those parts of the object defined by the superclass. This is why `plainbox` can’t access the `weight` field, even when it refers to a `BoxWeight` object. If you think about it, this makes sense, because the superclass has no knowledge of what a subclass adds to it. This is why the last line of code in the preceding fragment is commented out. It is not possible for a `Box` reference to access the `weight` field, because `Box` does not define one.

Although the preceding may seem a bit esoteric, it has some important practical applications—two of which are discussed later in this chapter.

**Using super**

In the preceding examples, classes derived from `Box` were not implemented as
efficiently or as robustly as they could have been. For example, the constructor for BoxWeight explicitly initializes the width, height, and depth fields of Box. Not only does this duplicate code found in its superclass, which is inefficient, but it implies that a subclass must be granted access to these members. However, there will be times when you will want to create a superclass that keeps the details of its implementation to itself (that is, that keeps its data members private). In this case, there would be no way for a subclass to directly access or initialize these variables on its own. Since encapsulation is a primary attribute of OOP, it is not surprising that Java provides a solution to this problem. Whenever a subclass needs to refer to its immediate superclass, it can do so by use of the keyword super.

super has two general forms. The first calls the superclass’ constructor. The second is used to access a member of the superclass that has been hidden by a member of a subclass. Each use is examined here.

Using super to Call Superclass Constructors
A subclass can call a constructor defined by its superclass by use of the following form of super:

    super(arg-list);

Here, arg-list specifies any arguments needed by the constructor in the superclass. super() must always be the first statement executed inside a subclass’ constructor.

To see how super() is used, consider this improved version of the BoxWeight class:

```java
// BoxWeight now uses super to initialize its Box attributes.
class BoxWeight extends Box {
    double weight; // weight of box

    // initialize width, height, and depth using super()
    BoxWeight(double w, double h, double d, double m) {
        super(w, h, d); // call superclass constructor
        weight = m;
    }
}
```

Here, BoxWeight() calls super() with the arguments w, h, and d. This causes the Box constructor to be called, which initializes width, height, and depth using these values. BoxWeight no longer initializes these values itself. It only needs to initialize the value unique to it: weight. This leaves Box free to make these values private if desired.
In the preceding example, `super()` was called with three arguments. Since constructors can be overloaded, `super()` can be called using any form defined by the superclass. The constructor executed will be the one that matches the arguments. For example, here is a complete implementation of `BoxWeight` that provides constructors for the various ways that a box can be constructed. In each case, `super()` is called using the appropriate arguments. Notice that `width, height, and depth` have been made private within `Box`.

```java
// A complete implementation of BoxWeight.
class Box {
    private double width;
    private double height;
    private double depth;

    // construct clone of an object
    Box(Box ob) { // pass object to constructor
        width = ob.width;
        height = ob.height;
        depth = ob.depth;
    }

    // constructor used when all dimensions specified
    Box(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }

    // constructor used when no dimensions specified
    Box() {
        width = -1; // use -1 to indicate
        height = -1; // an uninitialized
        depth = -1; // box
    }
```
// constructor used when cube is created
Box(double len) {
    width = height = depth = len;
}

// compute and return volume
double volume() {
    return width * height * depth;
}
}

// BoxWeight now fully implements all constructors.
class BoxWeight extends Box {
    double weight; // weight of box

    // construct clone of an object
    BoxWeight(BoxWeight ob) { // pass object to constructor
        super(ob);
        weight = ob.weight;
    }

    // constructor when all parameters are specified
    BoxWeight(double w, double h, double d, double m) {

super(w, h, d); // call superclass constructor
weight = m;
}

// default constructor
BoxWeight() {
    super();
    weight = -1;
}

// constructor used when cube is created
BoxWeight(double len, double m) {
    super(len);
    weight = m;
}
}

class DemoSuper {
    public static void main(String args[]) {
        BoxWeight mybox1 = new BoxWeight(10, 20, 15, 34.3);
        BoxWeight mybox2 = new BoxWeight(2, 3, 4, 0.076);
        BoxWeight mybox3 = new BoxWeight(); // default
        BoxWeight mycube = new BoxWeight(3, 2);
        BoxWeight myclone = new BoxWeight(mybox1);
        double vol;

        vol = mybox1.volume();
        System.out.println("Volume of mybox1 is " + vol);
        System.out.println("Weight of mybox1 is " + mybox1.weight);
        System.out.println();
    }
}
vol = mybox2.volume();
System.out.println("Volume of mybox2 is " + vol);
System.out.println("Weight of mybox2 is " + mybox2.weight);
System.out.println();

vol = mybox3.volume();
System.out.println("Volume of mybox3 is " + vol);
System.out.println("Weight of mybox3 is " + mybox3.weight);
System.out.println();

vol = myclone.volume();
System.out.println("Volume of myclone is " + vol);
System.out.println("Weight of myclone is " + myclone.weight);
System.out.println();

vol = mycube.volume();
System.out.println("Volume of mycube is " + vol);
System.out.println("Weight of mycube is " + mycube.weight);
System.out.println();
}

This program generates the following output:

Volume of mybox1 is 3000.0
Weight of mybox1 is 34.3

Volume of mybox2 is 24.0
Weight of mybox2 is 0.076

Volume of mybox3 is -1.0
Weight of mybox3 is -1.0

Volume of myclone is 3000.0
Weight of myclone is 34.3

Volume of mycube is 27.0
Weight of mycube is 2.0

Pay special attention to this constructor in BoxWeight:
Notice that `super()` is passed an object of type `BoxWeight`—not of type `Box`. This still invokes the constructor `Box(Box ob)`. As mentioned earlier, a superclass variable can be used to reference any object derived from that class. Thus, we are able to pass a `BoxWeight` object to the `Box` constructor. Of course, `Box` only has knowledge of its own members.

Let’s review the key concepts behind `super()`. When a subclass calls `super()`, it is calling the constructor of its immediate superclass. Thus, `super()` always refers to the superclass immediately above the calling class. This is true even in a multileveled hierarchy. Also, `super()` must always be the first statement executed inside a subclass constructor.

**A Second Use for super**

The second form of `super` acts somewhat like `this`, except that it always refers to the superclass of the subclass in which it is used. This usage has the following general form:

```
    super.member
```

Here, `member` can be either a method or an instance variable.

This second form of `super` is most applicable to situations in which member names of a subclass hide members by the same name in the superclass. Consider this simple class hierarchy:

```java
// Using super to overcome name hiding.
class A {
    int i;
}

// Create a subclass by extending class A.
```
class B extends A {
    int i; // this i hides the i in A
    
    B(int a, int b) {
        super.i = a; // i in A
        i = b; // i in B
    }
    
    void show() {
        System.out.println("i in superclass: " + super.i);
        System.out.println("i in subclass: " + i);
    }
}

class UseSuper {
    public static void main(String args[]) {
        B subOb = new B(1, 2);

        subOb.show();
    }
}

This program displays the following:

    i in superclass: 1
    i in subclass: 2

Although the instance variable i in B hides the i in A, super allows access to the i defined in the superclass. As you will see, super can also be used to call methods that are hidden by a subclass.

Creating a Multilevel Hierarchy

Up to this point, we have been using simple class hierarchies that consist of only a superclass and a subclass. However, you can build hierarchies that contain as many layers of inheritance as you like. As mentioned, it is perfectly acceptable to use a subclass as a superclass of another. For example, given three classes called A, B, and C, C can be a subclass of B, which is a subclass of A. When this type of situation occurs, each subclass inherits all of the traits found in all of its superclasses. In this case, C inherits all aspects of B and A. To see how a multilevel hierarchy can be useful, consider the following program. In it, the subclass BoxWeight is used as a superclass to create the subclass called Shipment. Shipment inherits all of the traits of BoxWeight and Box, and adds a field called cost, which holds the cost of
shipping such a parcel.

// Extend BoxWeight to include shipping costs.

// Start with Box.
class Box {
    private double width;
    private double height;
    private double depth;

    // construct clone of an object
    Box(Box ob) { // pass object to constructor
        width = ob.width;
        height = ob.height;
        depth = ob.depth;
    }

    // constructor used when all dimensions specified
    Box(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }

    // constructor used when no dimensions specified
    Box() {
        width = -1; // use -1 to indicate
        height = -1; // an uninitialized
        depth = -1; // box
    }

    // constructor used when cube is created
    Box(double len) {
        width = height = depth = len;
    }

    // compute and return volume
    double volume() {
        return width * height * depth;
    }
}
// Add weight.
class BoxWeight extends Box {
    double weight; // weight of box

    // construct clone of an object
    BoxWeight(BoxWeight ob) { // pass object to constructor
        super(ob);
        weight = ob.weight;
    }

    // constructor when all parameters are specified
    BoxWeight(double w, double h, double d, double m) {
        super(w, h, d); // call superclass constructor
        weight = m;
    }

    // default constructor
    BoxWeight() {
        super();
        weight = -1;
    }
}
// constructor used when cube is created
BoxWeight(double len, double m) {
    super(len);
    weight = m;
}

// Add shipping costs.
class Shipment extends BoxWeight {
    double cost;

    // construct clone of an object
    Shipment(Shipment ob) { // pass object to constructor
        super(ob);
        cost = ob.cost;
    }

    // constructor when all parameters are specified
    Shipment(double w, double h, double d,
             double m, double c) {
        super(w, h, d, m); // call superclass constructor
        cost = c;
    }
}
// default constructor
Shipment() {
    super();
    cost = -1;
}

// constructor used when cube is created
Shipment(double len, double m, double c) {
    super(len, m);
    cost = c;
}

class DemoShipment {
    public static void main(String args[]) {
        Shipment shipment1 =
            new Shipment(10, 20, 15, 10, 3.41);
        Shipment shipment2 =
            new Shipment(2, 3, 4, 0.76, 1.28);
        double vol;
        vol = shipment1.volume();
        System.out.println("Volume of shipment1 is " + vol);
        System.out.println("Weight of shipment1 is "
            + shipment1.weight);
        System.out.println("Shipping cost: $" + shipment1.cost)
        System.out.println();
        vol = shipment2.volume();
        System.out.println("Volume of shipment2 is " + vol);
        System.out.println("Weight of shipment2 is "
            + shipment2.weight);
        System.out.println("Shipping cost: $" + shipment2.cost);
    }
}

The output of this program is shown here:
Volume of shipment1 is 3000.0
Weight of shipment1 is 10.0
Shipping cost: $3.41

Volume of shipment2 is 24.0
Weight of shipment2 is 0.76
Shipping cost: $1.28

Because of inheritance, **Shipment** can make use of the previously defined classes of **Box** and **BoxWeight**, adding only the extra information it needs for its own, specific application. This is part of the value of inheritance; it allows the reuse of code.

This example illustrates one other important point: **super()** always refers to the constructor in the closest superclass. The **super()** in **Shipment** calls the constructor in **BoxWeight**. The **super()** in **BoxWeight** calls the constructor in **Box**. In a class hierarchy, if a superclass constructor requires parameters, then all subclasses must pass those parameters “up the line.” This is true whether or not a subclass needs parameters of its own.

**NOTE** In the preceding program, the entire class hierarchy, including **Box**, **BoxWeight**, and **Shipment**, is shown all in one file. This is for your convenience only. In Java, all three classes could have been placed into their own files and compiled separately. In fact, using separate files is the norm, not the exception, in creating class hierarchies.

**When Constructors Are Executed**

When a class hierarchy is created, in what order are the constructors for the classes that make up the hierarchy executed? For example, given a subclass called **B** and a superclass called **A**, is **A**’s constructor executed before **B**’s, or vice versa? The answer is that in a class hierarchy, constructors complete their execution in order of derivation, from superclass to subclass. Further, since **super()** must be the first statement executed in a subclass’ constructor, this order is the same whether or not **super()** is used. If **super()** is not used, then the default or parameterless constructor of each superclass will be executed. The following program illustrates when constructors are executed:
// Demonstrate when constructors are executed.

// Create a super class.
class A {
    A() {
        System.out.println("Inside A's constructor.");
    }
}

// Create a subclass by extending class A.
class B extends A {
    B() {
        System.out.println("Inside B's constructor.");
    }
}

// Create another subclass by extending B.
class C extends B {
    C() {
        System.out.println("Inside C's constructor.");
    }
}

class CallingCons {
    public static void main(String args[]) {
        C c = new C();
    }
}

The output from this program is shown here:

Inside A's constructor
Inside B's constructor
Inside C's constructor

As you can see, the constructors are executed in order of derivation.

If you think about it, it makes sense that constructors complete their execution in order of derivation. Because a superclass has no knowledge of any subclass, any initialization it needs to perform is separate from and possibly prerequisite to any initialization performed by the subclass. Therefore, it must complete its execution first.

Method Overriding
In a class hierarchy, when a method in a subclass has the same name and type signature as a method in its superclass, then the method in the subclass is said to **override** the method in the superclass. When an overridden method is called from within its subclass, it will always refer to the version of that method defined by the subclass. The version of the method defined by the superclass will be hidden.

Consider the following:

```java
// Method overriding.
class A {
    int i, j;
    A(int a, int b) {
        i = a;
        j = b;
    }

    // display i and j
    void show() {
        System.out.println("i and j: " + i + " " + j);
    }
}

class B extends A {
    int k;
    B(int a, int b, int c) {
        super(a, b);
        k = c;
    }

    // display k - this overrides show() in A
    void show() {
        System.out.println("k: " + k);
    }
}

class Override {
    public static void main(String args[]) {
        B subOb = new B(1, 2, 3);

        subOb.show(); // this calls show() in B
    }
}
```

The output produced by this program is shown here:
When `show()` is invoked on an object of type `B`, the version of `show()` defined within `B` is used. That is, the version of `show()` inside `B` overrides the version declared in `A`.

If you wish to access the superclass version of an overridden method, you can do so by using `super`. For example, in this version of `B`, the superclass version of `show()` is invoked within the subclass’ version. This allows all instance variables to be displayed.

```java
class B extends A {
    int k;

    B(int a, int b, int c) {
        super(a, b);
        k = c;
    }

    void show() {
        super.show(); // this calls A’s show()
        System.out.println("k: " + k);
    }
}
```

If you substitute this version of `A` into the previous program, you will see the following output:

```
i and j: 1 2
k: 3
```

Here, `super.show()` calls the superclass version of `show()`.

Method overriding occurs only when the names and the type signatures of the two methods are identical. If they are not, then the two methods are simply overloaded. For example, consider this modified version of the preceding example:
// Methods with differing type signatures are overloaded - not
// overridden.
class A {
    int i, j;

    A(int a, int b) {
        i = a;
        j = b;
    }

    // display i and j
    void show() {
        System.out.println("i and j: " + i + " " + j);
    }
}

// Create a subclass by extending class A.
class B extends A {
    int k;

    B(int a, int b, int c) {
        super(a, b);
        k = c;
    }

    // overload show()
    void show(String msg) {
        System.out.println(msg + k);
    }
}

class Override {
    public static void main(String args[]) {
        B subOb = new B(1, 2, 3);

        subOb.show("This is k: "); // this calls show() in B
        subOb.show(); // this calls show() in A
    }
}

The output produced by this program is shown here:

This is k: 3
i and j: 1 2
The version of `show( )` in B takes a string parameter. This makes its type signature different from the one in A, which takes no parameters. Therefore, no overriding (or name hiding) takes place. Instead, the version of `show( )` in B simply overloads the version of `show( )` in A.

**Dynamic Method Dispatch**

While the examples in the preceding section demonstrate the mechanics of method overriding, they do not show its power. Indeed, if there were nothing more to method overriding than a name space convention, then it would be, at best, an interesting curiosity, but of little real value. However, this is not the case. Method overriding forms the basis for one of Java’s most powerful concepts: *dynamic method dispatch*. Dynamic method dispatch is the mechanism by which a call to an overridden method is resolved at run time, rather than compile time. Dynamic method dispatch is important because this is how Java implements run-time polymorphism.

Let’s begin by restating an important principle: a superclass reference variable can refer to a subclass object. Java uses this fact to resolve calls to overridden methods at run time. Here is how. When an overridden method is called through a superclass reference, Java determines which version of that method to execute based upon the type of the object being referred to at the time the call occurs. Thus, this determination is made at run time. When different types of objects are referred to, different versions of an overridden method will be called. In other words, *it is the type of the object being referred to* (not the type of the reference variable) that determines which version of an overridden method will be executed. Therefore, if a superclass contains a method that is overridden by a subclass, then when different types of objects are referred to through a superclass reference variable, different versions of the method are executed.

Here is an example that illustrates dynamic method dispatch:
// Dynamic Method Dispatch
class A {
    void callme() {
        System.out.println("Inside A's callme method");
    }
}

class B extends A {
    // override callme()
    void callme() {
        System.out.println("Inside B's callme method");
    }
}

class C extends A {
    // override callme()
    void callme() {
        System.out.println("Inside C's callme method");
    }
}

class Dispatch {
    public static void main(String args[]) {
        A a = new A(); // object of type A
        B b = new B(); // object of type B
        C c = new C(); // object of type C

        A r; // obtain a reference of type A
        r = a; // r refers to an A object
        r.callme(); // calls A's version of callme

        r = b; // r refers to a B object
        r.callme(); // calls B's version of callme

        r = c; // r refers to a C object
        r.callme(); // calls C's version of callme
    }
}

The output from the program is shown here:
Inside A's callme method
Inside B's callme method
Inside C's callme method
This program creates one superclass called A and two subclasses of it, called B and C. Subclasses B and C override callme() declared in A. Inside the main() method, objects of type A, B, and C are declared. Also, a reference of type A, called r, is declared. The program then in turn assigns a reference to each type of object to r and uses that reference to invoke callme(). As the output shows, the version of callme() executed is determined by the type of object being referred to at the time of the call. Had it been determined by the type of the reference variable, r, you would see three calls to A’s callme() method.

NOTE Readers familiar with C++ or C# will recognize that overridden methods in Java are similar to virtual functions in those languages.

Why Overridden Methods?
As stated earlier, overridden methods allow Java to support run-time polymorphism. Polymorphism is essential to object-oriented programming for one reason: it allows a general class to specify methods that will be common to all of its derivatives, while allowing subclasses to define the specific implementation of some or all of those methods. Overridden methods are another way that Java implements the “one interface, multiple methods” aspect of polymorphism.

Part of the key to successfully applying polymorphism is understanding that the superclasses and subclasses form a hierarchy which moves from lesser to greater specialization. Used correctly, the superclass provides all elements that a subclass can use directly. It also defines those methods that the derived class must implement on its own. This allows the subclass the flexibility to define its own methods, yet still enforces a consistent interface. Thus, by combining inheritance with overridden methods, a superclass can define the general form of the methods that will be used by all of its subclasses.

Dynamic, run-time polymorphism is one of the most powerful mechanisms that object-oriented design brings to bear on code reuse and robustness. The ability of existing code libraries to call methods on instances of new classes without recompiling while maintaining a clean abstract interface is a profoundly powerful tool.

Applying Method Overriding
Let’s look at a more practical example that uses method overriding. The following program creates a superclass called Figure that stores the dimensions of a two-dimensional object. It also defines a method called area() that computes the area of an object. The program derives two subclasses from Figure. The first is Rectangle
and the second is **Triangle**. Each of these subclasses overrides `area()` so that it returns the area of a rectangle and a triangle, respectively.

```java
// Using run-time polymorphism.
class Figure {
    double dim1;
    double dim2;

    Figure(double a, double b) {
        dim1 = a;
        dim2 = b;
    }

    double area() {
        System.out.println("Area for Figure is undefined.");
        return 0;
    }
}

class Rectangle extends Figure {
    Rectangle(double a, double b) {
        super(a, b);
    }

    // override area for rectangle
    double area() {
        System.out.println("Inside Area for Rectangle.");
        return dim1 * dim2;
    }
}
```
class Triangle extends Figure {
    Triangle(double a, double b) {
        super(a, b);
    }
}

// override area for right triangle
double area() {
    System.out.println("Inside Area for Triangle.");
    return dim1 * dim2 / 2;
}

class FindAreas {
    public static void main(String args[]) {
        Figure f = new Figure(10, 10);
        Rectangle r = new Rectangle(9, 5);

        Triangle t = new Triangle(10, 8);
        Figure figref;

        figref = r;
        System.out.println("Area is "+ figref.area());

        figref = t;
        System.out.println("Area is "+ figref.area());

        figref = f;
        System.out.println("Area is "+ figref.area());
    }
}

The output from the program is shown here:

Inside Area for Rectangle.
Area is 45
Inside Area for Triangle.
Area is 40
Area for Figure is undefined.
Area is 0

Through the dual mechanisms of inheritance and run-time polymorphism, it is possible to define one consistent interface that is used by several different, yet
related, types of objects. In this case, if an object is derived from Figure, then its area can be obtained by calling area(). The interface to this operation is the same no matter what type of figure is being used.

**Using Abstract Classes**

There are situations in which you will want to define a superclass that declares the structure of a given abstraction without providing a complete implementation of every method. That is, sometimes you will want to create a superclass that only defines a generalized form that will be shared by all of its subclasses, leaving it to each subclass to fill in the details. Such a class determines the nature of the methods that the subclasses must implement. One way this situation can occur is when a superclass is unable to create a meaningful implementation for a method. This is the case with the class Figure used in the preceding example. The definition of area() is simply a placeholder. It will not compute and display the area of any type of object.

As you will see as you create your own class libraries, it is not uncommon for a method to have no meaningful definition in the context of its superclass. You can handle this situation two ways. One way, as shown in the previous example, is to simply have it report a warning message. While this approach can be useful in certain situations—such as debugging—it is not usually appropriate. You may have methods that must be overridden by the subclass in order for the subclass to have any meaning. Consider the class Triangle. It has no meaning if area() is not defined. In this case, you want some way to ensure that a subclass does, indeed, override all necessary methods. Java’s solution to this problem is the abstract method.

You can require that certain methods be overridden by subclasses by specifying the abstract type modifier. These methods are sometimes referred to as subclasser responsibility because they have no implementation specified in the superclass. Thus, a subclass must override them—it cannot simply use the version defined in the superclass. To declare an abstract method, use this general form:

```
abstract type name(parameter-list);
```

As you can see, no method body is present.

Any class that contains one or more abstract methods must also be declared abstract. To declare a class abstract, you simply use the abstract keyword in front of the class keyword at the beginning of the class declaration. There can be no objects of an abstract class. That is, an abstract class cannot be directly instantiated with the new operator. Such objects would be useless, because an abstract class is not fully defined. Also, you cannot declare abstract constructors, or abstract static methods. Any subclass of an abstract class must either implement all of the abstract methods
in the superclass, or be declared **abstract** itself.

Here is a simple example of a class with an abstract method, followed by a class which implements that method:

```java
// A Simple demonstration of abstract.
abstract class A {
    abstract void callme();

    // concrete methods are still allowed in abstract classes
    void callmetoo() {
        System.out.println("This is a concrete method.");
    }
}

class B extends A {
    void callme() {
        System.out.println("B's implementation of callme.");
    }
}

class AbstractDemo {
    public static void main(String args[]) {
        B b = new B();

        b.callme();
        b.callmetoo();
    }
}
```

Notice that no objects of class **A** are declared in the program. As mentioned, it is not possible to instantiate an abstract class. One other point: class **A** implements a concrete method called **callmetoo()**. This is perfectly acceptable. Abstract classes can include as much implementation as they see fit.

Although abstract classes cannot be used to instantiate objects, they can be used to create object references, because Java’s approach to run-time polymorphism is implemented through the use of superclass references. Thus, it must be possible to create a reference to an abstract class so that it can be used to point to a subclass object. You will see this feature put to use in the next example.

Using an abstract class, you can improve the **Figure** class shown earlier. Since there is no meaningful concept of area for an undefined two-dimensional figure, the following version of the program declares **area()** as abstract inside **Figure**. This, of course, means that all classes derived from **Figure** must override **area()**.
// Using abstract methods and classes.
abstract class Figure {
    double dim1;
    double dim2;

    Figure(double a, double b) {
        dim1 = a;
        dim2 = b;
    }

    // area is now an abstract method
    abstract double area();
}

class Rectangle extends Figure {
    Rectangle(double a, double b) {
        super(a, b);
    }

    // override area for rectangle
    double area() {
        System.out.println("Inside Area for Rectangle.");
        return dim1 * dim2;
    }
}
As the comment inside `main()` indicates, it is no longer possible to declare objects of type `Figure`, since it is now abstract. And, all subclasses of `Figure` must override `area()`. To prove this to yourself, try creating a subclass that does not override `area()`. You will receive a compile-time error.

Although it is not possible to create an object of type `Figure`, you can create a reference variable of type `Figure`. The variable `figref` is declared as a reference to `Figure`, which means that it can be used to refer to an object of any class derived from `Figure`. As explained, it is through superclass reference variables that overridden methods are resolved at run time.

### Using final with Inheritance

The keyword `final` has three uses. First, it can be used to create the equivalent of a named constant. This use was described in the preceding chapter. The other two uses of `final` apply to inheritance. Both are examined here.
Using final to Prevent Overriding

While method overriding is one of Java’s most powerful features, there will be times when you will want to prevent it from occurring. To disallow a method from being overridden, specify `final` as a modifier at the start of its declaration. Methods declared as `final` cannot be overridden. The following fragment illustrates `final`:

```java
class A {
    final void meth() {
        System.out.println("This is a final method.");
    }
}
class B extends A {
    void meth() { // ERROR! Can't override.
        System.out.println("Illegal!");
    }
}
```

Because `meth()` is declared as `final`, it cannot be overridden in `B`. If you attempt to do so, a compile-time error will result.

Methods declared as `final` can sometimes provide a performance enhancement: The compiler is free to `inline` calls to them because it “knows” they will not be overridden by a subclass. When a small `final` method is called, often the Java compiler can copy the bytecode for the subroutine directly inline with the compiled code of the calling method, thus eliminating the costly overhead associated with a method call. Inlining is an option only with `final` methods. Normally, Java resolves calls to methods dynamically, at run time. This is called `late binding`. However, since `final` methods cannot be overridden, a call to one can be resolved at compile time. This is called `early binding`.

Using final to Prevent Inheritance

Sometimes you will want to prevent a class from being inherited. To do this, precede the class declaration with `final`. Declaring a class as `final` implicitly declares all of its methods as `final`, too. As you might expect, it is illegal to declare a class as both `abstract` and `final` since an abstract class is incomplete by itself and relies upon its subclasses to provide complete implementations.

Here is an example of a `final` class:
As the comments imply, it is illegal for B to inherit A since A is declared as final.

The Object Class

There is one special class, Object, defined by Java. All other classes are subclasses of Object. That is, Object is a superclass of all other classes. This means that a reference variable of type Object can refer to an object of any other class. Also, since arrays are implemented as classes, a variable of type Object can also refer to any array.

Object defines the following methods, which means that they are available in every object.
<table>
<thead>
<tr>
<th>Method</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object clone( )</td>
<td>Creates a new object that is the same as the object being cloned.</td>
</tr>
<tr>
<td>boolean equals(Object object)</td>
<td>Determines whether one object is equal to another.</td>
</tr>
<tr>
<td>void finalize( )</td>
<td>Called before an unused object is recycled. (Deprecated by JDK 9.)</td>
</tr>
<tr>
<td>Class&lt;?&gt; getClass( )</td>
<td>Obtains the class of an object at run time.</td>
</tr>
<tr>
<td>int hashCode( )</td>
<td>Returns the hash code associated with the invoking object.</td>
</tr>
<tr>
<td>void notify( )</td>
<td>Resumes execution of a thread waiting on the invoking object.</td>
</tr>
<tr>
<td>void notifyAll( )</td>
<td>Resumes execution of all threads waiting on the invoking object.</td>
</tr>
<tr>
<td>String toString( )</td>
<td>Returns a string that describes the object.</td>
</tr>
<tr>
<td>void wait( )</td>
<td>Waits on another thread of execution.</td>
</tr>
<tr>
<td>void wait(long milliseconds)</td>
<td></td>
</tr>
<tr>
<td>void wait(long milliseconds,</td>
<td></td>
</tr>
<tr>
<td>int nanoseconds)</td>
<td></td>
</tr>
</tbody>
</table>

The methods `getClass( )`, `notify( )`, `notifyAll( )`, and `wait( )` are declared as **final**. You may override the others. These methods are described elsewhere in this book. However, notice two methods now: `equals( )` and `toString( )`. The `equals( )` method compares two objects. It returns `true` if the objects are equal, and `false` otherwise. The precise definition of equality can vary, depending on the type of objects being compared. The `toString( )` method returns a string that contains a description of the object on which it is called. Also, this method is automatically called when an object is output using `println( )`. Many classes override this method. Doing so allows them to tailor a description specifically for the types of objects that they create.

One last point: Notice the unusual syntax in the return type for `getClass( )`. This relates to Java’s `generics` feature, which is described in Chapter 14.
CHAPTER
This chapter examines two of Java’s most innovative features: packages and interfaces. Packages are containers for classes. They are used to keep the class name space compartmentalized. For example, a package allows you to create a class named List, which you can store in your own package without concern that it will collide with some other class named List stored elsewhere. Packages are stored in a hierarchical manner and are explicitly imported into new class definitions. As you will see in Chapter 16, packages also play an important role in the new modules feature added by JDK 9.

In previous chapters, you have seen how methods define the interface to the data in a class. Through the use of the interface keyword, Java allows you to fully abstract an interface from its implementation. Using interface, you can specify a set of methods that can be implemented by one or more classes. In its traditional form, the interface, itself, does not actually define any implementation. Although they are similar to abstract classes, interfaces have an additional capability: A class can implement more than one interface. By contrast, a class can only inherit a single superclass (abstract or otherwise).

Packages

In the preceding chapters, the name of each example class was taken from the same name space. This means that a unique name had to be used for each class to avoid name collisions. After a while, without some way to manage the name space, you could run out of convenient, descriptive names for individual classes. You also need some way to be assured that the name you choose for a class will be reasonably unique and not collide with class names chosen by other programmers. (Imagine a small group of programmers fighting over who gets to use the name “Foobar” as a class name. Or, imagine the entire Internet community arguing over who first named a class “Espresso.”) Thankfully, Java provides a mechanism for partitioning the class name space into more manageable chunks. This mechanism is the package. The package is both a naming and a visibility control mechanism. You can define classes inside a package that are not accessible by code outside that package. You can also define class members that are exposed only to other members of the same package. This allows your classes to have intimate knowledge of each other, but not expose
that knowledge to the rest of the world.

**Defining a Package**

To create a package is quite easy: simply include a `package` command as the first statement in a Java source file. Any classes declared within that file will belong to the specified package. The `package` statement defines a name space in which classes are stored. If you omit the `package` statement, the class names are put into the default package, which has no name. (This is why you haven’t had to worry about packages before now.) While the default package is fine for short, sample programs, it is inadequate for real applications. Most of the time, you will define a package for your code.

This is the general form of the `package` statement:

```
package pkg;
```

Here, `pkg` is the name of the package. For example, the following statement creates a package called `mypackage`:

```
package mypackage;
```

Java uses file system directories to store packages. For example, the `.class` files for any classes you declare to be part of `mypackage` must be stored in a directory called `mypackage`. Remember that case is significant, and the directory name must match the package name exactly.

More than one file can include the same `package` statement. The `package` statement simply specifies to which package the classes defined in a file belong. It does not exclude other classes in other files from being part of that same package. Most real-world packages are spread across many files.

You can create a hierarchy of packages. To do so, simply separate each package name from the one above it by use of a period. The general form of a multileveled package statement is shown here:

```
package pkg1.[pkg2.[pkg3]];
```

A package hierarchy must be reflected in the file system of your Java development system. For example, a package declared as

```
package a.b.c;
```

needs to be stored in `a\b\c` in a Windows environment. Be sure to choose your
package names carefully. You cannot rename a package without renaming the directory in which the classes are stored.

Finding Packages and CLASSPATH

As just explained, packages are mirrored by directories. This raises an important question: How does the Java run-time system know where to look for packages that you create? As it relates to the examples in this chapter, the answer has three parts. First, by default, the Java run-time system uses the current working directory as its starting point. Thus, if your package is in a subdirectory of the current directory, it will be found. Second, you can specify a directory path or paths by setting the CLASSPATH environmental variable. Third, you can use the -classpath option with java and javac to specify the path to your classes. It is useful to point out that, beginning with JDK 9, a package can be part of a module, and thus found on the module path. However, a discussion of modules and module paths is deferred until Chapter 16. For now, we will use only class paths.

For example, consider the following package specification:

```java
package mypack;
```

In order for a program to find mypack, the program can be executed from a directory immediately above mypack, or the CLASSPATH must be set to include the path to mypack, or the -classpath option must specify the path to mypack when the program is run via java.

When the second two options are used, the class path must not include mypack, itself. It must simply specify the path to mypack. For example, in a Windows environment, if the path to mypack is

```
C:\MyPrograms\Java\mypack
```

then the class path to mypack is

```
C:\MyPrograms\Java
```

The easiest way to try the examples shown in this book is to simply create the package directories below your current development directory, put the .class files into the appropriate directories, and then execute the programs from the development directory. This is the approach used in the following example.

A Short Package Example

Keeping the preceding discussion in mind, you can try this simple package:
// A simple package
package mypack;

class Balance {
    String name;
    double bal;

    Balance(String n, double b) {
        name = n;
        bal = b;
    }

    void show() {
        if(bal<0)
            System.out.print("-- > ");
        System.out.println(name + ": $" + bal);
    }
}

class AccountBalance {
    public static void main(String args[]) {
        Balance current[] = new Balance[3];
        current[0] = new Balance("K. J. Fielding", 123.23);
        current[1] = new Balance("Will Tell", 157.02);
        current[2] = new Balance("Tom Jackson", -12.33);

        for(int i=0; i<3; i++) current[i].show();
    }
}

Call this file AccountBalance.java and put it in a directory called mypack.

Next, compile the file. Make sure that the resulting .class file is also in the mypack directory. Then, try executing the AccountBalance class, using the following command line:

java mypack.AccountBalance

Remember, you will need to be in the directory above mypack when you execute this command. (Alternatively, you can use one of the other two options described in the preceding section to specify the path mypack.)

As explained, AccountBalance is now part of the package mypack. This means that it cannot be executed by itself. That is, you cannot use this command line:

java AccountBalance
AccountBalance must be qualified with its package name.

**Packages and Member Access**

In the preceding chapters, you learned about various aspects of Java’s access control mechanism and its access modifiers. For example, you already know that access to a **private** member of a class is granted only to other members of that class. Packages add another dimension to access control. As you will see, Java provides many levels of protection to allow fine-grained control over the visibility of variables and methods within classes, subclasses, and packages.

Classes and packages are both means of encapsulating and containing the name space and scope of variables and methods. Packages act as containers for classes and other subordinate packages. Classes act as containers for data and code. The class is Java’s smallest unit of abstraction. As it relates to the interplay between classes and packages, Java addresses four categories of visibility for class members:

- Subclasses in the same package
- Non-subclasses in the same package
- Subclasses in different packages
- Classes that are neither in the same package nor subclasses

The three access modifiers, **private**, **public**, and **protected**, provide a variety of ways to produce the many levels of access required by these categories. **Table 9-1** sums up the interactions.

<table>
<thead>
<tr>
<th></th>
<th>Private</th>
<th>No Modifier</th>
<th>Protected</th>
<th>Public</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same class</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Same package subclass</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Same package non-subclass</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Different package subclass</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Different package non-subclass</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Table 9-1  Class Member Access**

While Java’s access control mechanism may seem complicated, we can simplify it as follows. Anything declared **public** can be accessed from different classes and different packages. Anything declared **private** cannot be seen outside of its class. When a member does not have an explicit access specification, it is visible to
subclasses as well as to other classes in the same package. This is the default access. If you want to allow an element to be seen outside your current package, but only to classes that subclass your class directly, then declare that element **protected**.

**Table 9-1** applies only to members of classes. A non-nested class has only two possible access levels: default and public. When a class is declared as **public**, it is accessible outside its package. If a class has default access, then it can only be accessed by other code within its same package. When a class is public, it must be the only public class declared in the file, and the file must have the same name as the class.

---

**NOTE** The modules feature added by JDK 9 can also affect accessibility. Modules are described in **Chapter 16**.

**An Access Example**

The following example shows all combinations of the access control modifiers. This example has two packages and five classes. Remember that the classes for the two different packages need to be stored in directories named after their respective packages—in this case, **p1** and **p2**.

The source for the first package defines three classes: **Protection**, **Derived**, and **SamePackage**. The first class defines four **int** variables in each of the legal protection modes. The variable **n** is declared with the default protection, **n_pri** is private, **n_pro** is protected, and **n_pub** is public.

Each subsequent class in this example will try to access the variables in an instance of this class. The lines that will not compile due to access restrictions are commented out. Before each of these lines is a comment listing the places from which this level of protection would allow access.

The second class, **Derived**, is a subclass of **Protection** in the same package, **p1**. This grants **Derived** access to every variable in **Protection** except for **n_pri**, the private one. The third class, **SamePackage**, is not a subclass of **Protection**, but is in the same package and also has access to all but **n_pri**.

This is file **Protection.java**:
package p1;

public class Protection {
    int n = 1;
    private int n_pri = 2;
    protected int n_pro = 3;
    public int n_pub = 4;

    public Protection() {
        System.out.println("base constructor");
        System.out.println("n = " + n);
        System.out.println("n_pri = " + n_pri);
        System.out.println("n_pro = " + n_pro);
        System.out.println("n_pub = " + n_pub);
    }
}

This is file Derived.java:

package p1;

class Derived extends Protection {
    Derived() {
        System.out.println("derived constructor");
        System.out.println("n = " + n);

        // class only
        // System.out.println("n_pri = "4 + n_pri);

        System.out.println("n_pro = " + n_pro);
        System.out.println("n_pub = " + n_pub);
    }
}

This is file SamePackage.java:
Following is the source code for the other package, **p2**. The two classes defined in **p2** cover the other two conditions that are affected by access control. The first class, **Protection2**, is a subclass of **p1.Protection**. This grants access to all of **p1.Protection**’s variables except for **n_pri** (because it is **private**) and **n**, the variable declared with the default protection. Remember, the default only allows access from within the class or the package, not extra-package subclasses. Finally, the class **OtherPackage** has access to only one variable, **n_pub**, which was declared **public**.

This is file **Protection2.java**:

```java
package p1;

class SamePackage {
    SamePackage() {
        Protection p = new Protection();
        System.out.println("same package constructor");
        System.out.println("n = " + p.n);

        // class only
        // System.out.println("n_pri = " + p.n_pri);

        System.out.println("n_pro = " + p.n_pro);
        System.out.println("n_pub = " + p.n_pub);
    }
}
```

```java
package p2;

class Protection2 extends p1.Protection {
    Protection2() {
        System.out.println("derived other package constructor");

        // class or package only
        // System.out.println("n = " + n);

        // class only
        // System.out.println("n_pri = " + n_pri);

        System.out.println("n_pro = " + n_pro);
        System.out.println("n_pub = " + n_pub);
    }
}
```
This is file OtherPackage.java:

```java
package p2;

class OtherPackage {
    OtherPackage() {
        p1.Protection p = new p1.Protection();
        System.out.println("other package constructor");

        // class or package only
        // System.out.println("n = " + p.n);

        // class only
        // System.out.println("n_pri = " + p.n_pri);

        // class, subclass or package only
        // System.out.println("n_pro = " + p.n_pro);

        System.out.println("n_pub = " + p.n_pub);
    }
}

If you want to try these two packages, here are two test files you can use. The one for package p1 is shown here:

// Demo package p1.
package p1;

// Instantiate the various classes in p1.
public class Demo {
    public static void main(String args[]) {
        Protection ob1 = new Protection();
        Derived ob2 = new Derived();
        SamePackage ob3 = new SamePackage();
    }
}

The test file for p2 is shown next:
Importing Packages

Given that packages exist and are a good mechanism for compartmentalizing diverse classes from each other, it is easy to see why all of the built-in Java classes are stored in packages. There are no core Java classes in the unnamed default package; all of the standard classes are stored in some named package. Since classes within packages must be fully qualified with their package name or names, it could become tedious to type in the long dot-separated package path name for every class you want to use. For this reason, Java includes the import statement to bring certain classes, or entire packages, into visibility. Once imported, a class can be referred to directly, using only its name. The import statement is a convenience to the programmer and is not technically needed to write a complete Java program. If you are going to refer to a few dozen classes in your application, however, the import statement will save a lot of typing.

In a Java source file, import statements occur immediately following the package statement (if it exists) and before any class definitions. This is the general form of the import statement:

    import pkg1 [ .pkg2 ] . (classname | *);

Here, pkg1 is the name of a top-level package, and pkg2 is the name of a subordinate package inside the outer package separated by a dot (.). There is no practical limit on the depth of a package hierarchy, except that imposed by the file system. Finally, you specify either an explicit classname or a star (*), which indicates that the Java compiler should import the entire package. This code fragment shows both forms in use:

    import java.util.Date;
    import java.io.*;

// Demo package p2.
package p2;

// Instantiate the various classes in p2.
public class Demo {
    public static void main(String args[]) {
        Protection2 ob1 = new Protection2();
        OtherPackage ob2 = new OtherPackage();
    }
}
All of the standard Java SE classes included with Java begin with the name `java`. The basic language functions are stored in a package called `java.lang`. Normally, you have to import every package or class that you want to use, but since Java is useless without much of the functionality in `java.lang`, it is implicitly imported by the compiler for all programs. This is equivalent to the following line being at the top of all of your programs:

```java
import java.lang.*;
```

If a class with the same name exists in two different packages that you import using the star form, the compiler will remain silent, unless you try to use one of the classes. In that case, you will get a compile-time error and have to explicitly name the class specifying its package.

It must be emphasized that the `import` statement is optional. Any place you use a class name, you can use its `fully qualified name`, which includes its full package hierarchy. For example, this fragment uses an import statement:

```java
import java.util.*;

class MyDate extends Date {
}
```

The same example without the `import` statement looks like this:

```java
class MyDate extends java.util.Date {
}
```

In this version, `Date` is fully-qualified.

As shown in Table 9-1, when a package is imported, only those items within the package declared as `public` will be available to non-subclasses in the importing code. For example, if you want the `Balance` class of the package `mypack` shown earlier to be available as a stand-alone class for general use outside of `mypack`, then you will need to declare it as `public` and put it into its own file, as shown here:
package mypack;

/**< Now, the Balance class, its constructor, and its 
   show() method are public. This means that they can 
   be used by non-subclass code outside their package. */
public class Balance {
    String name;
    double bal;

    public Balance(String n, double b) {
        name = n;
        bal = b;
    }

    public void show() {
        if(bal<0)
            System.out.print("--> ");
        System.out.println(name + ": $" + bal);
    }
}

As you can see, the **Balance** class is now **public**. Also, its constructor and its **show()** method are **public**, too. This means that they can be accessed by any type of code outside the **mypack** package. For example, here **TestBalance** imports **mypack** and is then able to make use of the **Balance** class:

```java
import mypack.*;

class TestBalance {
    public static void main(String args[]) {
        /* Because Balance is public, you may use Balance 
           class and call its constructor. */
        Balance test = new Balance("J. J. Jaspers", 99.88);

        test.show(); // you may also call show()
    }
}
```

As an experiment, remove the **public** specifier from the **Balance** class and then try compiling **TestBalance**. As explained, errors will result.
Interfaces

Using the keyword `interface`, you can fully abstract a class’ interface from its implementation. That is, using `interface`, you can specify what a class must do, but not how it does it. Interfaces are syntactically similar to classes, but they lack instance variables, and, as a general rule, their methods are declared without any body. In practice, this means that you can define interfaces that don’t make assumptions about how they are implemented. Once it is defined, any number of classes can implement an `interface`. Also, one class can implement any number of interfaces.

To implement an interface, a class must provide the complete set of methods required by the interface. However, each class is free to determine the details of its own implementation. By providing the `interface` keyword, Java allows you to fully utilize the “one interface, multiple methods” aspect of polymorphism.

Interfaces are designed to support dynamic method resolution at run time. Normally, in order for a method to be called from one class to another, both classes need to be present at compile time so the Java compiler can check to ensure that the method signatures are compatible. This requirement by itself makes for a static and nonextensible classing environment. Inevitably in a system like this, functionality gets pushed up higher and higher in the class hierarchy so that the mechanisms will be available to more and more subclasses. Interfaces are designed to avoid this problem. They disconnect the definition of a method or set of methods from the inheritance hierarchy. Since interfaces are in a different hierarchy from classes, it is possible for classes that are unrelated in terms of the class hierarchy to implement the same interface. This is where the real power of interfaces is realized.

Defining an Interface

An interface is defined much like a class. This is a simplified general form of an interface:
When no access modifier is included, then default access results, and the interface is only available to other members of the package in which it is declared. When it is declared as `public`, the interface can be used by code outside its package. In this case, the interface must be the only public interface declared in the file, and the file must have the same name as the interface. `name` is the name of the interface, and can be any valid identifier. Notice that the methods that are declared have no bodies. They end with a semicolon after the parameter list. They are, essentially, abstract methods. Each class that includes such an interface must implement all of the methods.

Before continuing an important point needs to be made. Recently, a feature was added to `interface` that makes a significant change to its capabilities. Prior to JDK 8, an interface could not define any implementation whatsoever. This is the type of interface that the preceding simplified form shows, in which no method declaration supplies a body. Thus, prior to JDK 8, an interface could define only “what,” but not “how.” JDK 8 changed this. Beginning with JDK 8, it is possible to add a `default implementation` to an interface method. Furthermore, JDK 8 also added static interface methods, and beginning with JDK 9, an interface can include private methods. Thus, it is now possible for `interface` to specify some behavior. However, such methods constitute what are, in essence, special-use features, and the original intent behind `interface` still remains. Therefore, as a general rule, you will still often create and use interfaces in which no use is made of these new features. For this reason, we will begin by discussing the interface in its traditional form. The new interface features are described at the end of this chapter.

As the general form shows, variables can be declared inside interface declarations. They are implicitly `final` and `static`, meaning they cannot be changed by the implementing class. They must also be initialized. All methods and variables are implicitly `public`.

Here is an example of an interface definition. It declares a simple interface that
contains one method called \texttt{callback()} that takes a single integer parameter.

```java
interface Callback {
    void callback(int param);
}
```

\section*{Implementing Interfaces}

Once an \texttt{interface} has been defined, one or more classes can implement that interface. To implement an interface, include the \texttt{implements} clause in a class definition, and then create the methods required by the interface. The general form of a class that includes the \texttt{implements} clause looks like this:

```java
class \texttt{classname} \texttt{[extends superclass]} \texttt{[implements interface [,interface...]]} {
    // class-body
}
```

If a class implements more than one interface, the interfaces are separated with a comma. If a class implements two interfaces that declare the same method, then the same method will be used by clients of either interface. The methods that implement an interface must be declared \texttt{public}. Also, the type signature of the implementing method must match exactly the type signature specified in the \texttt{interface} definition.

Here is a small example class that implements the \texttt{Callback} interface shown earlier:

```java
class Client implements Callback {
    // Implement Callback's interface
    public void callback(int p) {
        System.out.println("callback called with " + p);
    }
}
```

Notice that \texttt{callback()} is declared using the \texttt{public} access modifier.

\textbf{REMEMBER} When you implement an interface method, it must be declared as \texttt{public}.

It is both permissible and common for classes that implement interfaces to define additional members of their own. For example, the following version of \texttt{Client} implements \texttt{callback()} and adds the method \texttt{nonIfaceMeth()}:
Accessing Implementations Through Interface References
You can declare variables as object references that use an interface rather than a class type. Any instance of any class that implements the declared interface can be referred to by such a variable. When you call a method through one of these references, the correct version will be called based on the actual instance of the interface being referred to. This is one of the key features of interfaces. The method to be executed is looked up dynamically at run time, allowing classes to be created later than the code which calls methods on them. The calling code can dispatch through an interface without having to know anything about the “callee.” This process is similar to using a superclass reference to access a subclass object, as described in Chapter 8.

The following example calls the `callback()` method via an interface reference variable:

```java
class Client implements Callback {
    // Implement Callback's interface
    public void callback(int p) {
        System.out.println("callback called with " + p);
    }

    void nonIfaceMeth() {
        System.out.println("Classes that implement interfaces " +
                          "may also define other members, too.");
    }
}
```

The output of this program is shown here:

```
callback called with 42
```

Notice that variable `c` is declared to be of the interface type `Callback`, yet it was assigned an instance of `Client`. Although `c` can be used to access the `callback()` method, it cannot access any other members of the `Client` class. An interface reference variable has knowledge only of the methods declared by its `interface` declaration. Thus, `c` could not be used to access `nonIfaceMeth()` since it is defined
by Client but not Callback.

While the preceding example shows, mechanically, how an interface reference variable can access an implementation object, it does not demonstrate the polymorphic power of such a reference. To sample this usage, first create the second implementation of Callback, shown here:

```java
// Another implementation of Callback.
class AnotherClient implements Callback {
    // Implement Callback's interface
    public void callback(int p) {
        System.out.println("Another version of callback");
        System.out.println("p squared is " + (p*p));
    }
}
```

Now, try the following class:

```java
class TestInterface2 {
    public static void main(String args[]) {
        Callback c = new Client();
        AnotherClient ob = new AnotherClient();

        c.callback(42);

        c = ob; // c now refers to AnotherClient object
        c.callback(42);
    }
}
```

The output from this program is shown here:

```
callback called with 42
Another version of callback
p squared is 1764
```

As you can see, the version of `callback()` that is called is determined by the type of object that `c` refers to at run time. While this is a very simple example, you will see another, more practical one shortly.

**Partial Implementations**

If a class includes an interface but does not fully implement the methods required by that interface, then that class must be declared as `abstract`. For example:
abstract class Incomplete implements Callback {
    int a, b;

    void show() {
        System.out.println(a + " " + b);
    }
    //...
}

Here, the class **Incomplete** does not implement **callback( )** and must be declared as **abstract**. Any class that inherits **Incomplete** must implement **callback( )** or be declared **abstract** itself.

### Nested Interfaces

An interface can be declared a member of a class or another interface. Such an interface is called a **member interface** or a **nested interface**. A nested interface can be declared as **public, private**, or **protected**. This differs from a top-level interface, which must either be declared as **public** or use the default access level, as previously described. When a nested interface is used outside of its enclosing scope, it must be qualified by the name of the class or interface of which it is a member. Thus, outside of the class or interface in which a nested interface is declared, its name must be fully qualified.

Here is an example that demonstrates a nested interface:

```
// A nested interface example.

// This class contains a member interface.
class A {
    // this is a nested interface
    public interface NestedIF {
        boolean isNotNegative(int x);
    }
}
```
Notice that A defines a member interface called NestedIF and that it is declared public. Next, B implements the nested interface by specifying

implements A.NestedIF

Notice that the name is fully qualified by the enclosing class’ name. Inside the main( ) method, an A.NestedIF reference called nif is created, and it is assigned a reference to a B object. Because B implements A.NestedIF, this is legal.

**Applying Interfaces**

To understand the power of interfaces, let’s look at a more practical example. In earlier chapters, you developed a class called Stack that implemented a simple fixed-size stack. However, there are many ways to implement a stack. For example, the stack can be of a fixed size or it can be “growable.” The stack can also be held in an array, a linked list, a binary tree, and so on. No matter how the stack is implemented, the interface to the stack remains the same. That is, the methods push( ) and pop( ) define the interface to the stack independently of the details of the implementation. Because the interface to a stack is separate from its implementation, it is easy to define a stack interface, leaving it to each implementation to define the specifics. Let’s look at two examples.

First, here is the interface that defines an integer stack. Put this in a file called IntStack.java. This interface will be used by both stack implementations.
// Define an integer stack interface.
interface IntStack {
    void push(int item); // store an item
    int pop(); // retrieve an item
}

The following program creates a class called FixedStack that implements a fixed-length version of an integer stack:

// An implementation of IntStack that uses fixed storage.
class FixedStack implements IntStack {
    private int stck[];
    private int tos;

    // allocate and initialize stack
    FixedStack(int size) {
        stck = new int[size];
        tos = -1;
    }

    // Push an item onto the stack
    public void push(int item) {
        if(tos==stck.length-1) // use length member
            System.out.println("Stack is full.");
        else
            stck[++tos] = item;
    }

    // Pop an item from the stack
    public int pop() {
        if(tos < 0) {
            System.out.println("Stack underflow.");
            return 0;
        }
        else
            return stck[tos--];
    }
}
Following is another implementation of `IntStack` that creates a dynamic stack by use of the same `interface` definition. In this implementation, each stack is constructed with an initial length. If this initial length is exceeded, then the stack is increased in size. Each time more room is needed, the size of the stack is doubled.
// Implement a "growable" stack.
class DynStack implements IntStack {
    private int stck[];
    private int tos;

    // allocate and initialize stack
    DynStack(int size) {
        stck = new int[size];
        tos = -1;
    }

    // Push an item onto the stack
    public void push(int item) {
        // if stack is full, allocate a larger stack
        if (tos == stck.length - 1) {
            int temp[] = new int[stck.length * 2]; // double size
            for (int i = 0; i < stck.length; i++) temp[i] = stck[i];
            stck = temp;
            stck[++tos] = item;
        } else
            stck[++tos] = item;
    }
The following class uses both the FixedStack and DynStack implementations. It does so through an interface reference. This means that calls to push() and pop() are resolved at run time rather than at compile time.
In this program, `mystack` is a reference to the `IntStack` interface. Thus, when it refers to `ds`, it uses the versions of `push()` and `pop()` defined by the `DynStack` implementation. When it refers to `fs`, it uses the versions of `push()` and `pop()` defined by `FixedStack`. As explained, these determinations are made at run time. Accessing multiple implementations of an interface through an interface reference variable is the most powerful way that Java achieves run-time polymorphism.

**Variables in Interfaces**

You can use interfaces to import shared constants into multiple classes by simply declaring an interface that contains variables that are initialized to the desired values. When you include that interface in a class (that is, when you “implement” the interface), all of those variable names will be in scope as constants. If an interface contains no methods, then any class that includes such an interface doesn’t actually implement anything. It is as if that class were importing the constant fields into the
class name space as **final** variables. The next example uses this technique to implement an automated “decision maker”:

```java
import java.util.Random;

interface SharedConstants {
    int NO = 0;
    int YES = 1;
    int MAYBE = 2;
    int LATER = 3;
    int SOON = 4;
    int NEVER = 5;
}

class Question implements SharedConstants {
    Random rand = new Random();
    int ask() {
        int prob = (int) (100 * rand.nextDouble());
        if (prob < 30)
            return NO;       // 30%
        else if (prob < 60)
            return YES;      // 30%
        else if (prob < 75)
            return LATER;    // 15%
        else if (prob < 98)
            return SOON;     // 13%
        else
            return NEVER;    // 2%
    }
}
```
Notice that this program makes use of one of Java’s standard classes: `Random`. This class provides pseudorandom numbers. It contains several methods that allow you to obtain random numbers in the form required by your program. In this example, the method `nextDouble()` is used. It returns random numbers in the range 0.0 to 1.0.

In this sample program, the two classes, `Question` and `AskMe`, both implement the `SharedConstants` interface where `NO`, `YES`, `MAYBE`, `SOON`, `LATER`, and `NEVER` are defined. Inside each class, the code refers to these constants as if each class had defined or inherited them directly. Here is the output of a sample run of

```java
class AskMe implements SharedConstants {
    static void answer(int result) {
        switch(result) {
            case NO:
                System.out.println("No");
                break;
            case YES:
                System.out.println("Yes");
                break;
            case MAYBE:
                System.out.println("Maybe");
                break;
            case LATER:
                System.out.println("Later");
                break;
            case SOON:
                System.out.println("Soon");
                break;
            case NEVER:
                System.out.println("Never");
                break;
        }
    }
}

public static void main(String args[]) {
    Question q = new Question();

    answer(q.ask());
    answer(q.ask());
    answer(q.ask());
    answer(q.ask());
    answer(q.ask());
}
```
this program. Note that the results are different each time it is run.

Later
Soon
No
Yes

NOTE The technique of using an interface to define shared constants, as just described, is controversial. It is described here for completeness.

**Interfaces Can Be Extended**

One interface can inherit another by use of the keyword `extends`. The syntax is the same as for inheriting classes. When a class implements an interface that inherits another interface, it must provide implementations for all methods required by the interface inheritance chain. Following is an example:

```java
// One interface can extend another.
interface A {
    void meth1();
    void meth2();
}

// B now includes meth1() and meth2() -- it adds meth3().
interface B extends A {
    void meth3();
}
```
As an experiment, you might want to try removing the implementation for `meth1()` in `MyClass`. This will cause a compile-time error. As stated earlier, any class that implements an interface must implement all methods required by that interface, including any that are inherited from other interfaces.

**Default Interface Methods**

As explained earlier, prior to JDK 8, an interface could not define any implementation whatsoever. This meant that for all previous versions of Java, the methods specified by an interface were abstract, containing no body. This is the traditional form of an interface and is the type of interface that the preceding discussions have used. The release of JDK 8 changed this by adding a new capability to `interface` called the default method. A default method lets you define a default implementation for an interface method. In other words, by use of a default method, it is possible for an interface method to provide a body, rather than being abstract. During its development, the default method was also referred to as an extension method, and you will likely see both terms used.
A primary motivation for the default method was to provide a means by which interfaces could be expanded without breaking existing code. Recall that there must be implementations for all methods defined by an interface. In the past, if a new method were added to a popular, widely used interface, then the addition of that method would break existing code because no implementation would be found for that new method. The default method solves this problem by supplying an implementation that will be used if no other implementation is explicitly provided. Thus, the addition of a default method will not cause preexisting code to break.

Another motivation for the default method was the desire to specify methods in an interface that are, essentially, optional, depending on how the interface is used. For example, an interface might define a group of methods that act on a sequence of elements. One of these methods might be called `remove()`, and its purpose is to remove an element from the sequence. However, if the interface is intended to support both modifiable and nonmodifiable sequences, then `remove()` is essentially optional because it won’t be used by nonmodifiable sequences. In the past, a class that implemented a nonmodifiable sequence would have had to define an empty implementation of `remove()`, even though it was not needed. Today, a default implementation for `remove()` can be specified in the interface that does nothing (or throws an exception). Providing this default prevents a class used for nonmodifiable sequences from having to define its own, placeholder version of `remove()`. Thus, by providing a default, the interface makes the implementation of `remove()` by a class optional.

It is important to point out that the addition of default methods does not change a key aspect of interface: its inability to maintain state information. An interface still cannot have instance variables, for example. Thus, the defining difference between an interface and a class is that a class can maintain state information, but an interface cannot. Furthermore, it is still not possible to create an instance of an interface by itself. It must be implemented by a class. Therefore, even though, beginning with JDK 8, an interface can define default methods, the interface must still be implemented by a class if an instance is to be created.

One last point: As a general rule, default methods constitute a special-purpose feature. Interfaces that you create will still be used primarily to specify what and not how. However, the inclusion of the default method gives you added flexibility.

**Default Method Fundamentals**

An interface default method is defined similar to the way a method is defined by a class. The primary difference is that the declaration is preceded by the keyword `default`. For example, consider this simple interface:
public interface MyIF {
    // This is a "normal" interface method declaration.
    // It does NOT define a default implementation.
    int getNumber();

    // This is a default method. Notice that it provides
    // a default implementation.
    default String getString() {
        return "Default String";
    }
}

MyIF declares two methods. The first, `getNumber()`, is a standard interface method declaration. It defines no implementation whatsoever. The second method is `getString()`, and it does include a default implementation. In this case, it simply returns the string "Default String". Pay special attention to the way `getString()` is declared. Its declaration is preceded by the `default` modifier. This syntax can be generalized. To define a default method, precede its declaration with `default`.

Because `getString()` includes a default implementation, it is not necessary for an implementing class to override it. In other words, if an implementing class does not provide its own implementation, the default is used. For example, the `MyIFImp` class shown next is perfectly valid:

```java
// Implement MyIF.
class MyIFImp implements MyIF {
    // Only getNumber() defined by MyIF needs to be implemented.
    // getString() can be allowed to default.
    public int getNumber() {
        return 100;
    }
}
```

The following code creates an instance of `MyIFImp` and uses it to call both `getNumber()` and `getString()`.
// Use the default method.
class DefaultMethodDemo {
    public static void main(String args[]) {

        MyIFImp obj = new MyIFImp();

        // Can call getNumber(), because it is explicitly
        // implemented by MyIFImp:
        System.out.println(obj.getNumber());

        // Can also call getString(), because of default
        // implementation:
        System.out.println(obj.getString());
    }
}

The output is shown here:

100
Default String

As you can see, the default implementation of getString() was automatically used. It was not necessary for MyIFImp to define it. Thus, for getString(), implementation by a class is optional. (Of course, its implementation by a class will be required if the class uses getString() for some purpose beyond that supported by its default.)

It is both possible and common for an implementing class to define its own implementation of a default method. For example, MyIFImp2 overrides getString():

class MyIFImp2 implements MyIF {
    // Here, implementations for both getNumber() and getString() are provided.
    public int getNumber() {
        return 100;
    }

    public String getString() {
        return "This is a different string.";
    }
}

Now, when getString() is called, a different string is returned.
A More Practical Example

Although the preceding shows the mechanics of using default methods, it doesn’t illustrate their usefulness in a more practical setting. To do this, let’s once again return to the `IntStack` interface shown earlier in this chapter. For the sake of discussion, assume that `IntStack` is widely used and many programs rely on it. Further assume that we now want to add a method to `IntStack` that clears the stack, enabling the stack to be re-used. Thus, we want to evolve the `IntStack` interface so that it defines new functionality, but we don’t want to break any preexisting code. In the past, this would be impossible, but with the inclusion of default methods, it is now easy to do. For example, the `IntStack` interface can be enhanced like this:

```java
interface IntStack {
    void push(int item); // store an item
    int pop(); // retrieve an item

    // Because clear() has a default, it need not be
    // implemented by a preexisting class that uses IntStack.
    default void clear() {
        System.out.println("clear() not implemented.");
    }
}
```

Here, the default behavior of `clear()` simply displays a message indicating that it is not implemented. This is acceptable because no preexisting class that implements `IntStack` would ever call `clear()` because it was not defined by the earlier version of `IntStack`. However, `clear()` can be implemented by a new class that implements `IntStack`. Furthermore, `clear()` needs to be defined by a new implementation only if it is used. Thus, the default method gives you

- a way to gracefully evolve interfaces over time, and
- a way to provide optional functionality without requiring that a class provide a placeholder implementation when that functionality is not needed.

One other point: In real-world code, `clear()` would have thrown an exception, rather than displaying an error message. Exceptions are described in the next chapter. After working through that material, you might want to try modifying `clear()` so that its default implementation throws an `UnsupportedOperationException`.

Multiple Inheritance Issues

As explained earlier in this book, Java does not support the multiple inheritance of
classes. Now that an interface can include default methods, you might be wondering if an interface can provide a way around this restriction. The answer is, essentially, no. Recall that there is still a key difference between a class and an interface: a class can maintain state information (especially through the use of instance variables), but an interface cannot.

The preceding notwithstanding, default methods do offer a bit of what one would normally associate with the concept of multiple inheritance. For example, you might have a class that implements two interfaces. If each of these interfaces provides default methods, then some behavior is inherited from both. Thus, to a limited extent, default methods do support multiple inheritance of behavior. As you might guess, in such a situation, it is possible that a name conflict will occur.

For example, assume that two interfaces called Alpha and Beta are implemented by a class called MyClass. What happens if both Alpha and Beta provide a method called reset( ) for which both declare a default implementation? Is the version by Alpha or the version by Beta used by MyClass? Or, consider a situation in which Beta extends Alpha. Which version of the default method is used? Or, what if MyClass provides its own implementation of the method? To handle these and other similar types of situations, Java defines a set of rules that resolves such conflicts.

First, in all cases, a class implementation takes priority over an interface default implementation. Thus, if MyClass provides an override of the reset( ) default method, MyClass’ version is used. This is the case even if MyClass implements both Alpha and Beta. In this case, both defaults are overridden by MyClass’ implementation.

Second, in cases in which a class implements two interfaces that both have the same default method, but the class does not override that method, then an error will result. Continuing with the example, if MyClass implements both Alpha and Beta, but does not override reset( ), then an error will occur.

In cases in which one interface inherits another, with both defining a common default method, the inheriting interface’s version of the method takes precedence. Therefore, continuing the example, if Beta extends Alpha, then Beta’s version of reset( ) will be used.

It is possible to explicitly refer to a default implementation in an inherited interface by using this form of super. Its general form is shown here:

```
InterfaceName.super.methodName()
```

For example, if Beta wants to refer to Alpha’s default for reset( ), it can use this statement:

```
Alpha.super.reset();
```
Use static Methods in an Interface

Another capability added to interface by JDK 8 is the ability to define one or more static methods. Like static methods in a class, a static method defined by an interface can be called independently of any object. Thus, no implementation of the interface is necessary, and no instance of the interface is required, in order to call a static method. Instead, a static method is called by specifying the interface name, followed by a period, followed by the method name. Here is the general form:

`InterfaceName.staticMethodName`

Notice that this is similar to the way that a static method in a class is called.

The following shows an example of a static method in an interface by adding one to `MyIF`, shown in the previous section. The static method is `getDefaultNumber()`.

It returns zero.

```java
public interface MyIF {
    // This is a "normal" interface method declaration.
    // It does NOT define a default implementation.
    int getNumber();

    // This is a default method. Notice that it provides
    // a default implementation.
    default String getString() { return "Default String";
    }

    // This is a static interface method.
    static int getDefaultNumber() { return 0;
    }
}
```

The `getDefaultNumber()` method can be called, as shown here:

```java
int defNum = MyIF.getDefaultNumber();
```

As mentioned, no implementation or instance of `MyIF` is required to call `getDefaultNumber()` because it is static.

One last point: static interface methods are not inherited by either an implementing class or a subinterface.
Private Interface Methods

Beginning with JDK 9, an interface can include a private method. A private interface method can be called only by a default method or another private method defined by the same interface. Because a private interface method is specified `private`, it cannot be used by code outside the interface in which it is defined. This restriction includes subinterfaces because a private interface method is not inherited by a subinterface.

The key benefit of a private interface method is that it lets two or more default methods use a common piece of code, thus avoiding code duplication. For example, here is another version of the `IntStack` interface that has two default methods called `popNElements()` and `skipAndPopNElements()`. The first returns an array that contains the top $N$ elements on the stack. The second skips a specified number of elements and then returns an array that contains the next $N$ elements. Both use a private method called `getElements()` to obtain an array of the specified number of elements from the stack.

```java
// Another version of IntStack that has a private interface
// method that is used by two default methods.
interface IntStack {
    void push(int item); // store an item
    int pop(); // retrieve an item
}```
Notice that both popNEElements() and skipAndPopNEElements() use the private getElements() method to obtain the array to return. This prevents both methods from having to duplicate the same code sequence. Keep in mind that because getElements() is private, it cannot be called by code outside IntStack. Thus, its use is limited to the default methods inside IntStack. Also, because getElements() uses the pop() method to obtain stack elements, it will automatically call the implementation of pop() provided by the IntStack is implementation. Thus, getElements() will work for any stack class that implements IntStack.

Although the private interface method is a feature that you will seldom need, in those cases in which you do need it, you will find it quite useful.

Final Thoughts on Packages and Interfaces
Although the examples we’ve included in this book do not make frequent use of
packages or interfaces, both of these tools are an important part of the Java programming environment. Virtually all real programs that you write in Java will be contained within packages. A number will probably implement interfaces as well. It is important, therefore, that you be comfortable with their usage.
10 Exception Handling

This chapter examines Java’s exception-handling mechanism. An exception is an abnormal condition that arises in a code sequence at run time. In other words, an exception is a run-time error. In computer languages that do not support exception handling, errors must be checked and handled manually—typically through the use of error codes, and so on. This approach is as cumbersome as it is troublesome. Java’s exception handling avoids these problems and, in the process, brings run-time error management into the object-oriented world.

Exception-Handling Fundamentals

A Java exception is an object that describes an exceptional (that is, error) condition that has occurred in a piece of code. When an exceptional condition arises, an object representing that exception is created and thrown in the method that caused the error. That method may choose to handle the exception itself, or pass it on. Either way, at some point, the exception is caught and processed. Exceptions can be generated by the Java run-time system, or they can be manually generated by your code. Exceptions thrown by Java relate to fundamental errors that violate the rules of the Java language or the constraints of the Java execution environment. Manually generated exceptions are typically used to report some error condition to the caller of a method.

Java exception handling is managed via five keywords: try, catch, throw, throws, and finally. Briefly, here is how they work. Program statements that you want to monitor for exceptions are contained within a try block. If an exception occurs within the try block, it is thrown. Your code can catch this exception (using catch) and handle it in some rational manner. System-generated exceptions are automatically thrown by the Java run-time system. To manually throw an exception, use the keyword throw. Any exception that is thrown out of a method must be specified as such by a throws clause. Any code that absolutely must be executed after a try block completes is put in a finally block.

This is the general form of an exception-handling block:
try {
    // block of code to monitor for errors
}

catch (ExceptionType1 exObj) {
    // exception handler for ExceptionType1
}

catch (ExceptionType2 exObj) {
    // exception handler for ExceptionType2
}
  // ...
finally {
    // block of code to be executed after try block ends
}

Here, ExceptionType is the type of exception that has occurred. The remainder of this chapter describes how to apply this framework.

NOTE There is another form of the try statement that supports automatic resource management. This form of try, called try-with-resources, is described in Chapter 13 in the context of managing files because files are some of the most commonly used resources.

### Exception Types

All exception types are subclasses of the built-in class Throwable. Thus, Throwable is at the top of the exception class hierarchy. Immediately below Throwable are two subclasses that partition exceptions into two distinct branches. One branch is headed by Exception. This class is used for exceptional conditions that user programs should catch. This is also the class that you will subclass to create your own custom exception types. There is an important subclass of Exception, called RuntimeException. Exceptions of this type are automatically defined for the programs that you write and include things such as division by zero and invalid array indexing.

The other branch is topped by Error, which defines exceptions that are not expected to be caught under normal circumstances by your program. Exceptions of type Error are used by the Java run-time system to indicate errors having to do with the run-time environment, itself. Stack overflow is an example of such an error. This
chapter will not be dealing with exceptions of type Error, because these are typically created in response to catastrophic failures that cannot usually be handled by your program.

The top-level exception hierarchy is shown here:

![Exception Hierarchy Diagram]

**Uncaught Exceptions**

Before you learn how to handle exceptions in your program, it is useful to see what happens when you don’t handle them. This small program includes an expression that intentionally causes a divide-by-zero error:

```java
class Exc0 {
    public static void main(String args[]) {
        int d = 0;
        int a = 42 / d;
    }
}
```

When the Java run-time system detects the attempt to divide by zero, it constructs a new exception object and then *throws* this exception. This causes the execution of Exc0 to stop, because once an exception has been thrown, it must be *caught* by an exception handler and dealt with immediately. In this example, we haven’t supplied any exception handlers of our own, so the exception is caught by the default handler provided by the Java run-time system. Any exception that is not caught by your program will ultimately be processed by the default handler. The default handler displays a string describing the exception, prints a stack trace from the point at which the exception occurred, and terminates the program.
Here is the exception generated when this example is executed:

java.lang.ArithmeticException: / by zero
    at Exc0.main(Exc0.java:4)

Notice how the class name, **Exc0**, the method name, **main**, the filename, **Exc0.java**, and the line number, **4**, are all included in the simple stack trace. Also, notice that the type of exception thrown is a subclass of **Exception** called **ArithmeticException**, which more specifically describes what type of error happened. As discussed later in this chapter, Java supplies several built-in exception types that match the various sorts of run-time errors that can be generated.

The stack trace will always show the sequence of method invocations that led up to the error. For example, here is another version of the preceding program that introduces the same error but in a method separate from **main( )**:

class Exc1 {
    static void subroutine() {
        int d = 0;
        int a = 10 / d;
    }
    public static void main(String args[]) {
        Exc1.subroutine();
    }
}

The resulting stack trace from the default exception handler shows how the entire call stack is displayed:

java.lang.ArithmeticException: / by zero
    at Exc1.subroutine(Exc1.java:4)
    at Exc1.main(Exc1.java:7)

As you can see, the bottom of the stack is **main**’s line 7, which is the call to **subroutine( )**, which caused the exception at line 4. The call stack is quite useful for debugging, because it pinpoints the precise sequence of steps that led to the error.

### Using try and catch

Although the default exception handler provided by the Java run-time system is useful for debugging, you will usually want to handle an exception yourself. Doing so provides two benefits. First, it allows you to fix the error. Second, it prevents the program from automatically terminating. Most users would be confused (to say the
least) if your program stopped running and printed a stack trace whenever an error occurred! Fortunately, it is quite easy to prevent this.

To guard against and handle a run-time error, simply enclose the code that you want to monitor inside a **try** block. Immediately following the **try** block, include a **catch** clause that specifies the exception type that you wish to catch. To illustrate how easily this can be done, the following program includes a **try** block and a **catch** clause that processes the **ArithmeticException** generated by the division-by-zero error:

```java
class Exc2 {
    public static void main(String args[]) {
        int d, a;

        try { // monitor a block of code.
            d = 0;
            a = 42 / d;
            System.out.println("This will not be printed.");
        } catch (ArithmeticException e) { // catch divide-by-zero error
            System.out.println("Division by zero.");
        }

        System.out.println("After catch statement.");
    }
}
```

This program generates the following output:

```
Division by zero.
After catch statement.
```

Notice that the call to **println( )** inside the **try** block is never executed. Once an exception is thrown, program control transfers out of the **try** block into the **catch** block. Put differently, **catch** is not “called,” so execution never “returns” to the **try** block from a **catch**. Thus, the line "This will not be printed." is not displayed. Once the **catch** statement has executed, program control continues with the next line in the program following the entire **try / catch** mechanism.

A **try** and its **catch** statement form a unit. The scope of the **catch** clause is restricted to those statements specified by the immediately preceding **try** statement. A **catch** statement cannot catch an exception thrown by another **try** statement (except in the case of nested **try** statements, described shortly). The statements that are protected by **try** must be surrounded by curly braces. (That is, they must be
within a block.) You cannot use try on a single statement.

The goal of most well-constructed catch clauses should be to resolve the exceptional condition and then continue on as if the error had never happened. For example, in the next program each iteration of the for loop obtains two random integers. Those two integers are divided by each other, and the result is used to divide the value 12345. The final result is put into a. If either division operation causes a divide-by-zero error, it is caught, the value of a is set to zero, and the program continues.

```
// Handle an exception and move on.
import java.util.Random;

class HandleError {
    public static void main(String args[]) {
        int a=0, b=0, c=0;
        Random r = new Random();

        for(int i=0; i<32000; i++) {
            try {
                b = r.nextInt();
                c = r.nextInt();
                a = 12345 / (b/c);
            } catch (ArithmeticException e) {
                System.out.println("Division by zero.");
                a = 0;  // set a to zero and continue
            }
            System.out.println("a: "+a);
        }
    }
}
```

### Displaying a Description of an Exception

Throwable overrides the toString() method (defined by Object) so that it returns a string containing a description of the exception. You can display this description in a println() statement by simply passing the exception as an argument. For example, the catch block in the preceding program can be rewritten like this:

```
catch (ArithmeticException e) {
    System.out.println("Exception: "+e);
    a = 0;  // set a to zero and continue
}
```
When this version is substituted in the program, and the program is run, each divide-
by-zero error displays the following message:

    Exception: java.lang.ArithmeticException: / by zero

While it is of no particular value in this context, the ability to display a
description of an exception is valuable in other circumstances—particularly when
you are experimenting with exceptions or when you are debugging.

Multiple catch Clauses

In some cases, more than one exception could be raised by a single piece of code. To
handle this type of situation, you can specify two or more catch clauses, each
catching a different type of exception. When an exception is thrown, each catch
statement is inspected in order, and the first one whose type matches that of the
exception is executed. After one catch statement executes, the others are bypassed,
and execution continues after the try / catch block. The following example traps two
different exception types:

```java
// Demonstrate multiple catch statements.
class MultipleCatches {
    public static void main(String args[]) {
        try {
            int a = args.length;
            System.out.println("a = " + a);
            int b = 42 / a;
            int c[] = { 1 };
            c[42] = 99;
        } catch (ArithmeticException e) {
            System.out.println("Divide by 0: " + e);
        } catch (ArrayIndexOutOfBoundsException e) {
            System.out.println("Array index oob: " + e);
        }
        System.out.println("After try/catch blocks.");
    }
}
```

This program will cause a division-by-zero exception if it is started with no
command-line arguments, since a will equal zero. It will survive the division if you
provide a command-line argument, setting a to something larger than zero. But it
will cause an ArrayIndexOutOfBoundsException, since the int array c has a
length of 1, yet the program attempts to assign a value to c[42].
Here is the output generated by running it both ways:

C:\>java MultipleCatches
a = 0
Divide by 0: java.lang.ArithmeticException: / by zero
After try/catch blocks.

C:\>java MultipleCatches TestArg
a = 1
Array index oob: java.lang.ArrayIndexOutOfBoundsException:42
After try/catch blocks.

When you use multiple catch statements, it is important to remember that exception subclasses must come before any of their superclasses. This is because a catch statement that uses a superclass will catch exceptions of that type plus any of its subclasses. Thus, a subclass would never be reached if it came after its superclass. Further, in Java, unreachable code is an error. For example, consider the following program:

/* This program contains an error.

A subclass must come before its superclass in a series of catch statements. If not, unreachable code will be created and a compile-time error will result.
*/
class SuperSubCatch {
   public static void main(String args[]) {
      try {
         int a = 0;
         int b = 42 / a;
      } catch(Exception e) {
         System.out.println("Generic Exception catch.");
      }
      /* This catch is never reached because ArithmeticException is a subclass of Exception. */
      catch(ArithmeticException e) { // ERROR - unreachable
         System.out.println("This is never reached.");
      }
   }
}

If you try to compile this program, you will receive an error message stating that the second catch statement is unreachable because the exception has already been
caught. Since ArithmeticException is a subclass of Exception, the first catch statement will handle all Exception-based errors, including ArithmeticException. This means that the second catch statement will never execute. To fix the problem, reverse the order of the catch statements.

Nested try Statements

The try statement can be nested. That is, a try statement can be inside the block of another try. Each time a try statement is entered, the context of that exception is pushed on the stack. If an inner try statement does not have a catch handler for a particular exception, the stack is unwound and the next try statement’s catch handlers are inspected for a match. This continues until one of the catch statements succeeds, or until all of the nested try statements are exhausted. If no catch statement matches, then the Java run-time system will handle the exception. Here is an example that uses nested try statements:
As you can see, this program nests one try block within another. The program works as follows. When you execute the program with no command-line arguments, a divide-by-zero exception is generated by the outer try block. Execution of the program with one command-line argument generates a divide-by-zero exception from within the nested try block. Since the inner block does not catch this exception, it is passed on to the outer try block, where it is handled. If you execute the program with two command-line arguments, an array boundary exception is generated from within the inner try block. Here are sample runs that illustrate each case:
Nesting of *try* statements can occur in less obvious ways when method calls are involved. For example, you can enclose a call to a method within a *try* block. Inside that method is another *try* statement. In this case, the *try* within the method is still nested inside the outer *try* block, which calls the method. Here is the previous program recoded so that the nested *try* block is moved inside the method `nesttry()`:

```java
/* Try statements can be implicitly nested via 
calls to methods. */
class MethNestTry {
    static void nesttry(int a) {
        try { // nested try block
            /* If one command-line arg is used, 
                then a divide-by-zero exception 
                will be generated by the following code. */
            if(a==1) a = a/(a-a); // division by zero

            /* If two command-line args are used, 
                then generate an out-of-bounds exception. */
            if(a==2) {
                int c[] = { 1 };
                c[42] = 99; // generate an out-of-bounds exception
            }
            } catch(ArrayIndexOutOfBoundsException e) {
                System.out.println("Array index out-of-bounds: " + e);
            }
    }
}
```
public static void main(String args[]) {
    try {
        int a = args.length;

        /* If no command-line args are present, 
         * the following statement will generate 
         * a divide-by-zero exception. */
        int b = 42 / a;
        System.out.println("a = " + a);

        nesttry(a);
    } catch(ArithmeticException e) {
        System.out.println("Divide by 0: " + e);
    }
}

The output of this program is identical to that of the preceding example.

throw

So far, you have only been catching exceptions that are thrown by the Java run-time system. However, it is possible for your program to throw an exception explicitly, using the throw statement. The general form of throw is shown here:

    throw ThrowableInstance;

Here, ThrowableInstance must be an object of type Throwable or a subclass of Throwable. Primitive types, such as int or char, as well as non-Throwable classes, such as String and Object, cannot be used as exceptions. There are two ways you can obtain a Throwable object: using a parameter in a catch clause or creating one with the new operator.

The flow of execution stops immediately after the throw statement; any subsequent statements are not executed. The nearest enclosing try block is inspected to see if it has a catch statement that matches the type of exception. If it does find a match, control is transferred to that statement. If not, then the next enclosing try statement is inspected, and so on. If no matching catch is found, then the default exception handler halts the program and prints the stack trace.

Here is a sample program that creates and throws an exception. The handler that catches the exception rethrows it to the outer handler.
This program gets two chances to deal with the same error. First, `main()` sets up an exception context and then calls `demoproc()`. The `demoproc()` method then sets up another exception-handling context and immediately throws a new instance of `NullPointerException`, which is caught on the next line. The exception is then rethrown. Here is the resulting output:

Caught inside demoproc.
Recaught: java.lang.NullPointerException: demo

The program also illustrates how to create one of Java’s standard exception objects. Pay close attention to this line:

```java
throw new NullPointerException("demo");
```

Here, `new` is used to construct an instance of `NullPointerException`. Many of Java’s built-in run-time exceptions have at least two constructors: one with no parameter and one that takes a string parameter. When the second form is used, the argument specifies a string that describes the exception. This string is displayed when the object is used as an argument to `println()` or `print()`. It can also be obtained by a call to `getMessage()`, which is defined by `Throwable`.

```java
throws
```
If a method is capable of causing an exception that it does not handle, it must specify this behavior so that callers of the method can guard themselves against that exception. You do this by including a `throws` clause in the method’s declaration. A `throws` clause lists the types of exceptions that a method might throw. This is necessary for all exceptions, except those of type `Error` or `RuntimeException`, or any of their subclasses. All other exceptions that a method can throw must be declared in the `throws` clause. If they are not, a compile-time error will result.

This is the general form of a method declaration that includes a `throws` clause:

```java
type method-name(parameter-list) throws exception-list
{
    // body of method
}
```

Here, `exception-list` is a comma-separated list of the exceptions that a method can throw.

Following is an example of an incorrect program that tries to throw an exception that it does not catch. Because the program does not specify a `throws` clause to declare this fact, the program will not compile.

```java
// This program contains an error and will not compile.
class ThrowsDemo {
    static void throwOne() {
        System.out.println("Inside throwOne.");
        throw new IllegalAccessException("demo");
    }
    public static void main(String args[]) {
        throwOne();
    }
}
```

To make this example compile, you need to make two changes. First, you need to declare that `throwOne()` throws `IllegalAccessException`. Second, `main()` must define a `try / catch` statement that catches this exception.

The corrected example is shown here:
Here is the output generated by running this example program:

```
inside throwOne
caught java.lang.IllegalArgumentException: demo
```

**finally**

When exceptions are thrown, execution in a method takes a rather abrupt, nonlinear path that alters the normal flow through the method. Depending upon how the method is coded, it is even possible for an exception to cause the method to return prematurely. This could be a problem in some methods. For example, if a method opens a file upon entry and closes it upon exit, then you will not want the code that closes the file to be bypassed by the exception-handling mechanism. The `finally` keyword is designed to address this contingency.

`finally` creates a block of code that will be executed after a `try /catch` block has completed and before the code following the `try/catch` block. The `finally` block will execute whether or not an exception is thrown. If an exception is thrown, the `finally` block will execute even if no `catch` statement matches the exception. Any time a method is about to return to the caller from inside a `try/catch` block, via an uncaught exception or an explicit return statement, the `finally` clause is also executed just before the method returns. This can be useful for closing file handles and freeing up any other resources that might have been allocated at the beginning of a method with the intent of disposing of them before returning. The `finally` clause is optional. However, each `try` statement requires at least one `catch` or a `finally` clause.

Here is an example program that shows three methods that exit in various ways, none without executing their `finally` clauses:
// Demonstrate finally.
class FinallyDemo {
    // Throw an exception out of the method.
    static void procA() {
        try {
            System.out.println("inside procA");
            throw new RuntimeException("demo");
        } finally {
            System.out.println("procA's finally");
        }
    }

    // Return from within a try block.
    static void procB() {
        try {
            System.out.println("inside procB");
            return;
        } finally {
            System.out.println("procB's finally");
        }
    }

    // Execute a try block normally.
    static void procC() {
        try {
            System.out.println("inside procC");
        } finally {
            System.out.println("procC's finally");
        }
    }

    public static void main(String args[]) {
        try {
            procA();
        } catch (Exception e) {
            System.out.println("Exception caught");
        }

        procB();
        procC();
    }
}
In this example, procA() prematurely breaks out of the try by throwing an exception. The finally clause is executed on the way out. procB()’s try statement is exited via a return statement. The finally clause is executed before procB() returns. In procC(), the try statement executes normally, without error. However, the finally block is still executed.

REMEMBER If a finally block is associated with a try, the finally block will be executed upon conclusion of the try.

Here is the output generated by the preceding program:

inside procA
procA's finally
Exception caught
inside procB
procB's finally
inside procC
procC's finally

Java’s Built-in Exceptions

Inside the standard package java.lang, Java defines several exception classes. A few have been used by the preceding examples. The most general of these exceptions are subclasses of the standard type RuntimeException. As previously explained, these exceptions need not be included in any method’s throws list. In the language of Java, these are called unchecked exceptions because the compiler does not check to see if a method handles or throws these exceptions. The unchecked exceptions defined in java.lang are listed in Table 10-1. Table 10-2 lists those exceptions defined by java.lang that must be included in a method’s throws list if that method can generate one of these exceptions and does not handle it itself. These are called checked exceptions. In addition to the exceptions in java.lang, Java defines several more that relate to its other standard packages.
<table>
<thead>
<tr>
<th>Exception</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>ArithmeticException</td>
<td>Arithmetic error, such as divide-by-zero.</td>
</tr>
<tr>
<td>ArrayIndexOutOfBoundsException</td>
<td>Array index is out-of-bounds.</td>
</tr>
<tr>
<td>ArrayStoreException</td>
<td>Assignment to an array element of an incompatible type.</td>
</tr>
<tr>
<td>ClassCastException</td>
<td>Invalid cast.</td>
</tr>
<tr>
<td>EnumConstantNotFoundException</td>
<td>An attempt is made to use an undefined enumeration value.</td>
</tr>
<tr>
<td>IllegalArgumentException</td>
<td>Illegal argument used to invoke a method.</td>
</tr>
<tr>
<td>IllegalCallerException</td>
<td>A method cannot be legally executed by the calling code. (Added by JDK 9.)</td>
</tr>
<tr>
<td>IllegalMonitorStateException</td>
<td>Illegal monitor operation, such as waiting on an unlocked thread.</td>
</tr>
<tr>
<td>IllegalStateException</td>
<td>Environment or application is in incorrect state.</td>
</tr>
<tr>
<td>IllegalThreadStateException</td>
<td>Requested operation not compatible with current thread state.</td>
</tr>
<tr>
<td>IndexOutOfBoundsException</td>
<td>Some type of index is out-of-bounds.</td>
</tr>
<tr>
<td>LayerInstantiationException</td>
<td>A module layer cannot be created. (Added by JDK 9.)</td>
</tr>
<tr>
<td>NegativeArraySizeException</td>
<td>Array created with a negative size.</td>
</tr>
<tr>
<td>NullPointerException</td>
<td>Invalid use of a null reference.</td>
</tr>
<tr>
<td>NumberFormatException</td>
<td>Invalid conversion of a string to a numeric format.</td>
</tr>
<tr>
<td>SecurityException</td>
<td>Attempt to violate security.</td>
</tr>
<tr>
<td>StringIndexOutOfBoundsException</td>
<td>Attempt to index outside the bounds of a string.</td>
</tr>
<tr>
<td>TypeNotFoundException</td>
<td>Type not found.</td>
</tr>
<tr>
<td>UnsupportedOperationException</td>
<td>An unsupported operation was encountered.</td>
</tr>
</tbody>
</table>

Table 10-1  Java’s Unchecked `RuntimeException` Subclasses Defined in `java.lang`
Creating Your Own Exception Subclasses

Although Java’s built-in exceptions handle most common errors, you will probably want to create your own exception types to handle situations specific to your applications. This is quite easy to do: just define a subclass of `Exception` (which is, of course, a subclass of `Throwable`). Your subclasses don’t need to actually implement anything—it is their existence in the type system that allows you to use them as exceptions.

The `Exception` class does not define any methods of its own. It does, of course, inherit those methods provided by `Throwable`. Thus, all exceptions, including those that you create, have the methods defined by `Throwable` available to them. They are shown in Table 10-3. You may also wish to override one or more of these methods in exception classes that you create.

<table>
<thead>
<tr>
<th>Exception</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>ClassNotFoundException</td>
<td>Class not found.</td>
</tr>
<tr>
<td>CloneNotSupportedException</td>
<td>Attempt to clone an object that does not implement the <code>Cloneable</code> interface.</td>
</tr>
<tr>
<td>IllegalAccessException</td>
<td>Access to a class is denied.</td>
</tr>
<tr>
<td>InstantiationException</td>
<td>Attempt to create an object of an abstract class or interface.</td>
</tr>
<tr>
<td>InterruptedException</td>
<td>One thread has been interrupted by another thread.</td>
</tr>
<tr>
<td>NoSuchFieldException</td>
<td>A requested field does not exist.</td>
</tr>
<tr>
<td>NoSuchMethodException</td>
<td>A requested method does not exist.</td>
</tr>
<tr>
<td>ReflectiveOperationException</td>
<td>Superclass of reflection-related exceptions.</td>
</tr>
</tbody>
</table>

Table 10-2  Java’s Checked Exceptions Defined in `java.lang`
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>final void addSuppressed(Throwables exc)</td>
<td>Adds exc to the list of suppressed exceptions associated with the invoking exception. Primarily for use by the <code>try-with-resources</code> statement.</td>
</tr>
<tr>
<td>Throwable fillInStackTrace()</td>
<td>Returns a Throwable object that contains a completed stack trace. This object can be rethrown.</td>
</tr>
<tr>
<td>Throwable getCause()</td>
<td>Returns the exception that underlies the current exception. If there is no underlying exception, <code>null</code> is returned.</td>
</tr>
<tr>
<td>String getLocalizedMessage()</td>
<td>Returns a localized description of the exception.</td>
</tr>
<tr>
<td>String getMessage()</td>
<td>Returns a description of the exception.</td>
</tr>
<tr>
<td>StackTraceElement[] getStackTrace()</td>
<td>Returns an array that contains the stack trace, one element at a time, as an array of <code>StackTraceElement</code>. The method at the top of the stack is the last method called before the exception was thrown. This method is found in the first element of the array. The <code>StackTraceElement</code> class gives your program access to information about each element in the trace, such as its method name.</td>
</tr>
<tr>
<td>final Throwable[] getSuppressed()</td>
<td>Obtains the suppressed exceptions associated with the invoking exception and returns an array that contains the result. Suppressed exceptions are primarily generated by the <code>try-with-resources</code> statement.</td>
</tr>
<tr>
<td>Throwable initCause(Throwables causeExc)</td>
<td>Associates causeExc with the invoking exception as a cause of the invoking exception. Returns a reference to the exception.</td>
</tr>
<tr>
<td>void printStackTrace()</td>
<td>Displays the stack trace.</td>
</tr>
<tr>
<td>void printStackTrace(PrintStream stream)</td>
<td>Sends the stack trace to the specified stream.</td>
</tr>
<tr>
<td>void printStackTrace(PrintWriter stream)</td>
<td>Sends the stack trace to the specified stream.</td>
</tr>
<tr>
<td>void setStackTrace(StackTraceElement elements[])</td>
<td>Sets the stack trace to the elements passed in elements. This method is for specialized applications, not normal use.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Returns a String object containing a description of the exception. This method is called by <code>println()</code> when outputting a Throwable object.</td>
</tr>
</tbody>
</table>
**Table 10-3** The Methods Defined by **Throwable**

**Exception** defines four public constructors. Two support chained exceptions, described in the next section. The other two are shown here:

```java
Exception() Exception(String msg)
```

The first form creates an exception that has no description. The second form lets you specify a description of the exception.

Although specifying a description when an exception is created is often useful, sometimes it is better to override `toString()`. Here’s why: The version of `toString()` defined by **Throwable** (and inherited by **Exception**) first displays the name of the exception followed by a colon, which is then followed by your description. By overriding `toString()`, you can prevent the exception name and colon from being displayed. This makes for a cleaner output, which is desirable in some cases.

The following example declares a new subclass of **Exception** and then uses that subclass to signal an error condition in a method. It overrides the `toString()` method, allowing a carefully tailored description of the exception to be displayed.
This example defines a subclass of `Exception` called `MyException`. This subclass is quite simple: It has only a constructor plus an overridden `toString()` method that displays the value of the exception. The `ExceptionDemo` class defines a method named `compute()` that throws a `MyException` object. The exception is thrown when `compute()`’s integer parameter is greater than 10. The `main()` method sets up an exception handler for `MyException`, then calls `compute()` with a legal value (less than 10) and an illegal one to show both paths through the code. Here is the result:

```
Called compute(1)
Normal exit
Called compute(20)
Caught MyException[20]
```
Chained Exceptions

Beginning with JDK 1.4, a feature was incorporated into the exception subsystem: chained exceptions. The chained exception feature allows you to associate another exception with an exception. This second exception describes the cause of the first exception. For example, imagine a situation in which a method throws an ArithmeticException because of an attempt to divide by zero. However, the actual cause of the problem was that an I/O error occurred, which caused the divisor to be set improperly. Although the method must certainly throw an ArithmeticException, since that is the error that occurred, you might also want to let the calling code know that the underlying cause was an I/O error. Chained exceptions let you handle this, and any other situation in which layers of exceptions exist.

To allow chained exceptions, two constructors and two methods were added to Throwable. The constructors are shown here:

```
Throwable(Throwable causeExc)
Throwable(String msg, Throwable causeExc)
```

In the first form, causeExc is the exception that causes the current exception. That is, causeExc is the underlying reason that an exception occurred. The second form allows you to specify a description at the same time that you specify a cause exception. These two constructors have also been added to the Error, Exception, and RuntimeException classes.

The chained exception methods supported by Throwable are getCause( ) and initCause( ). These methods are shown in Table 10-3 and are repeated here for the sake of discussion.

```
Throwable getCause( )
Throwable initCause(Throwable causeExc)
```

The getCause( ) method returns the exception that underlies the current exception. If there is no underlying exception, null is returned. The initCause( ) method associates causeExc with the invoking exception and returns a reference to the exception. Thus, you can associate a cause with an exception after the exception has been created. However, the cause exception can be set only once. Thus, you can call initCause( ) only once for each exception object. Furthermore, if the cause exception was set by a constructor, then you can’t set it again using initCause( ). In general, initCause( ) is used to set a cause for legacy exception classes that don’t support the two additional constructors described earlier.

Here is an example that illustrates the mechanics of handling chained exceptions:
The output from the program is shown here:

Caught: java.lang.NullPointerException: top layer
Original cause: java.lang.ArithmeticException: cause

In this example, the top-level exception is **NullPointerException**. To it is added a cause exception, **ArithmeticException**. When the exception is thrown out of `demoproc()`, it is caught by `main()`. There, the top-level exception is displayed, followed by the underlying exception, which is obtained by calling `getCause()`.

Chained exceptions can be carried on to whatever depth is necessary. Thus, the cause exception can, itself, have a cause. Be aware that overly long chains of exceptions may indicate poor design.

Chained exceptions are not something that every program will need. However, in cases in which knowledge of an underlying cause is useful, they offer an elegant solution.
Three Additional Exception Features

Beginning with JDK 7, three interesting and useful features have been part of the exception system. The first automates the process of releasing a resource, such as a file, when it is no longer needed. It is based on an expanded form of the `try` statement called `try-with-resources`, and is described in Chapter 13 when files are introduced. The second feature is called `multi-catch`, and the third is sometimes referred to as `final rethrow` or `more precise rethrow`. These two features are described here.

The multi-catch feature allows two or more exceptions to be caught by the same `catch` clause. It is not uncommon for two or more exception handlers to use the same code sequence even though they respond to different exceptions. Instead of having to catch each exception type individually, you can use a single `catch` clause to handle all of the exceptions without code duplication.

To use a multi-catch, separate each exception type in the `catch` clause with the OR operator. Each multi-catch parameter is implicitly `final`. (You can explicitly specify `final`, if desired, but it is not necessary.) Because each multi-catch parameter is implicitly `final`, it can’t be assigned a new value.

Here is a `catch` statement that uses the multi-catch feature to catch both `ArithmeticException` and `ArrayIndexOutOfBoundsException`:

```java
catch(ArithmeticException | ArrayIndexOutOfBoundsException e) {
```

The following program shows the multi-catch feature in action:
The program will generate an `ArithmeticException` when the division by zero is attempted. If you comment out the division statement and remove the comment symbol from the next line, an `ArrayIndexOutOfBoundsException` is generated. Both exceptions are caught by the single `catch` statement.

The more precise rethrow feature restricts the type of exceptions that can be rethrown to only those checked exceptions that the associated `try` block throws, that are not handled by a preceding `catch` clause, and that are a subtype or supertype of the parameter. Although this capability might not be needed often, it is now available for use. For the more precise rethrow feature to be in force, the `catch` parameter must be either effectively `final`, which means that it must not be assigned a new value inside the `catch` block, or explicitly declared `final`.

### Using Exceptions

Exception handling provides a powerful mechanism for controlling complex programs that have many dynamic run-time characteristics. It is important to think of `try`, `throw`, and `catch` as clean ways to handle errors and unusual boundary conditions in your program’s logic. Unlike some other languages in which error return codes are used to indicate failure, Java uses exceptions. Thus, when a method can fail, have it throw an exception. This is a cleaner way to handle failure modes.

One last point: Java’s exception-handling statements should not be considered a
general mechanism for nonlocal branching. If you do so, it will only confuse your code and make it hard to maintain.
CHAPTER
Java provides built-in support for *multithreaded programming*. A multithreaded program contains two or more parts that can run concurrently. Each part of such a program is called a *thread*, and each thread defines a separate path of execution. Thus, multithreading is a specialized form of multitasking.

You are almost certainly acquainted with multitasking because it is supported by virtually all modern operating systems. However, there are two distinct types of multitasking: process-based and thread-based. It is important to understand the difference between the two. For many readers, process-based multitasking is the more familiar form. A *process* is, in essence, a program that is executing. Thus, *process-based* multitasking is the feature that allows your computer to run two or more programs concurrently. For example, process-based multitasking enables you to run the Java compiler at the same time that you are using a text editor or visiting a web site. In process-based multitasking, a program is the smallest unit of code that can be dispatched by the scheduler.

In a *thread-based* multitasking environment, the thread is the smallest unit of dispatchable code. This means that a single program can perform two or more tasks simultaneously. For instance, a text editor can format text at the same time that it is printing, as long as these two actions are being performed by two separate threads. Thus, process-based multitasking deals with the “big picture,” and thread-based multitasking handles the details.

Multitasking threads require less overhead than multitasking processes. Processes are heavyweight tasks that require their own separate address spaces. Interprocess communication is expensive and limited. Context switching from one process to another is also costly. Threads, on the other hand, are lighter weight. They share the same address space and cooperatively share the same heavyweight process. Interthread communication is inexpensive, and context switching from one thread to the next is lower in cost. While Java programs make use of process-based multitasking environments, process-based multitasking is not under Java’s direct control. However, multithreaded multitasking is.

Multithreading enables you to write efficient programs that make maximum use of the processing power available in the system. One important way multithreading achieves this is by keeping idle time to a minimum. This is especially important for the interactive, networked environment in which Java operates because idle time is
common. For example, the transmission rate of data over a network is much slower than the rate at which the computer can process it. Even local file system resources are read and written at a much slower pace than they can be processed by the CPU. And, of course, user input is much slower than the computer. In a single-threaded environment, your program has to wait for each of these tasks to finish before it can proceed to the next one—even though most of the time the program is idle, waiting for input. Multithreading helps you reduce this idle time because another thread can run when one is waiting.

If you have programmed for operating systems such as Windows, then you are already familiar with multithreaded programming. However, the fact that Java manages threads makes multithreading especially convenient because many of the details are handled for you.

**The Java Thread Model**

The Java run-time system depends on threads for many things, and all the class libraries are designed with multithreading in mind. In fact, Java uses threads to enable the entire environment to be asynchronous. This helps reduce inefficiency by preventing the waste of CPU cycles.

The value of a multithreaded environment is best understood in contrast to its counterpart. Single-threaded systems use an approach called an *event loop* with *polling*. In this model, a single thread of control runs in an infinite loop, polling a single event queue to decide what to do next. Once this polling mechanism returns with, say, a signal that a network file is ready to be read, then the event loop dispatches control to the appropriate event handler. Until this event handler returns, nothing else can happen in the program. This wastes CPU time. It can also result in one part of a program dominating the system and preventing any other events from being processed. In general, in a single-threaded environment, when a thread *blocks* (that is, suspends execution) because it is waiting for some resource, the entire program stops running.

The benefit of Java’s multithreading is that the main loop/polling mechanism is eliminated. One thread can pause without stopping other parts of your program. For example, the idle time created when a thread reads data from a network or waits for user input can be utilized elsewhere. Multithreading allows animation loops to sleep for a second between each frame without causing the whole system to pause. When a thread blocks in a Java program, only the single thread that is blocked pauses. All other threads continue to run.

As most readers know, over the past few years, multi-core systems have become commonplace. Of course, single-core systems are still in widespread use. It is
important to understand that Java’s multithreading features work in both types of systems. In a single-core system, concurrently executing threads share the CPU, with each thread receiving a slice of CPU time. Therefore, in a single-core system, two or more threads do not actually run at the same time, but idle CPU time is utilized. However, in multi-core systems, it is possible for two or more threads to actually execute simultaneously. In many cases, this can further improve program efficiency and increase the speed of certain operations.

**NOTE** In addition to the multithreading features described in this chapter, you will also want to explore the Fork/Join Framework. It provides a powerful means of creating multithreaded applications that automatically scale to make best use of multi-core environments. The Fork/Join Framework is part of Java’s support for parallel programming, which is the name commonly given to the techniques that optimize some types of algorithms for parallel execution in systems that have more than one CPU. For a discussion of the Fork/Join Framework and other concurrency utilities, see Chapter 28. Java’s traditional multithreading capabilities are described here.

Threads exist in several states. Here is a general description. A thread can be running. It can be ready to run as soon as it gets CPU time. A running thread can be suspended, which temporarily halts its activity. A suspended thread can then be resumed, allowing it to pick up where it left off. A thread can be blocked when waiting for a resource. At any time, a thread can be terminated, which halts its execution immediately. Once terminated, a thread cannot be resumed.

**Thread Priorities**

Java assigns to each thread a priority that determines how that thread should be treated with respect to the others. Thread priorities are integers that specify the relative priority of one thread to another. As an absolute value, a priority is meaningless; a higher-priority thread doesn’t run any faster than a lower-priority thread if it is the only thread running. Instead, a thread’s priority is used to decide when to switch from one running thread to the next. This is called a context switch. The rules that determine when a context switch takes place are simple:

- A thread can voluntarily relinquish control. This occurs when explicitly yielding, sleeping, or when blocked. In this scenario, all other threads are examined, and the highest-priority thread that is ready to run is given the CPU.
- A thread can be preempted by a higher-priority thread. In this case, a lower-priority thread that does not yield the processor is simply preempted—no
matter what it is doing—by a higher-priority thread. Basically, as soon as a higher-priority thread wants to run, it does. This is called *preemptive multitasking*.

In cases where two threads with the same priority are competing for CPU cycles, the situation is a bit complicated. For some operating systems, threads of equal priority are time-sliced automatically in round-robin fashion. For other types of operating systems, threads of equal priority must voluntarily yield control to their peers. If they don’t, the other threads will not run.

**CAUTION** Portability problems can arise from the differences in the way that operating systems context-switch threads of equal priority.

**Synchronization**

Because multithreading introduces an asynchronous behavior to your programs, there must be a way for you to enforce synchronicity when you need it. For example, if you want two threads to communicate and share a complicated data structure, such as a linked list, you need some way to ensure that they don’t conflict with each other. That is, you must prevent one thread from writing data while another thread is in the middle of reading it. For this purpose, Java implements an elegant twist on an age-old model of interprocess synchronization: the *monitor*. The monitor is a control mechanism first defined by C.A.R. Hoare. You can think of a monitor as a very small box that can hold only one thread. Once a thread enters a monitor, all other threads must wait until that thread exits the monitor. In this way, a monitor can be used to protect a shared asset from being manipulated by more than one thread at a time.

In Java, there is no class “Monitor”; instead, each object has its own implicit monitor that is automatically entered when one of the object’s synchronized methods is called. Once a thread is inside a synchronized method, no other thread can call any other synchronized method on the same object. This enables you to write very clear and concise multithreaded code, because synchronization support is built into the language.

**Messaging**

After you divide your program into separate threads, you need to define how they will communicate with each other. When programming with some other languages, you must depend on the operating system to establish communication between threads. This, of course, adds overhead. By contrast, Java provides a clean, low-cost
way for two or more threads to talk to each other, via calls to predefined methods that all objects have. Java’s messaging system allows a thread to enter a synchronized method on an object, and then wait there until some other thread explicitly notifies it to come out.

The Thread Class and the Runnable Interface
Java’s multithreading system is built upon the Thread class, its methods, and its companion interface, Runnable. Thread encapsulates a thread of execution. Since you can’t directly refer to the ethereal state of a running thread, you will deal with it through its proxy, the Thread instance that spawned it. To create a new thread, your program will either extend Thread or implement the Runnable interface.

The Thread class defines several methods that help manage threads. Several of those used in this chapter are shown here:

<table>
<thead>
<tr>
<th>Method</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>getName</td>
<td>Obtain a thread’s name.</td>
</tr>
<tr>
<td>getPriority</td>
<td>Obtain a thread’s priority.</td>
</tr>
<tr>
<td>isAlive</td>
<td>Determine if a thread is still running.</td>
</tr>
<tr>
<td>join</td>
<td>Wait for a thread to terminate.</td>
</tr>
<tr>
<td>run</td>
<td>Entry point for the thread.</td>
</tr>
<tr>
<td>sleep</td>
<td>Suspend a thread for a period of time.</td>
</tr>
<tr>
<td>start</td>
<td>Start a thread by calling its run method.</td>
</tr>
</tbody>
</table>

Thus far, all the examples in this book have used a single thread of execution. The remainder of this chapter explains how to use Thread and Runnable to create and manage threads, beginning with the one thread that all Java programs have: the main thread.

The Main Thread
When a Java program starts up, one thread begins running immediately. This is usually called the main thread of your program, because it is the one that is executed when your program begins. The main thread is important for two reasons:

- It is the thread from which other “child” threads will be spawned.
- Often, it must be the last thread to finish execution because it performs various
shutdown actions.

Although the main thread is created automatically when your program is started, it can be controlled through a `Thread` object. To do so, you must obtain a reference to it by calling the method `currentThread()`, which is a `public static` member of `Thread`. Its general form is shown here:

```java
static Thread currentThread()
```

This method returns a reference to the thread in which it is called. Once you have a reference to the main thread, you can control it just like any other thread.

Let’s begin by reviewing the following example:

```java
// Controlling the main Thread.
class CurrentThreadDemo {
    public static void main(String args[]) {
        Thread t = Thread.currentThread();

        System.out.println("Current thread: " + t);

        // change the name of the thread
        t.setName("My Thread");
        System.out.println("After name change: " + t);

        try {
            for(int n = 5; n > 0; n--) {
                System.out.println(n);
                Thread.sleep(1000);
            }
        } catch (InterruptedException e) {
            System.out.println("Main thread interrupted");
        }
    }
}
```

In this program, a reference to the current thread (the main thread, in this case) is obtained by calling `currentThread()`, and this reference is stored in the local variable `t`. Next, the program displays information about the thread. The program then calls `setName()` to change the internal name of the thread. Information about the thread is then redisplayed. Next, a loop counts down from five, pausing one second between each line. The pause is accomplished by the `sleep()` method. The argument to `sleep()` specifies the delay period in milliseconds. Notice the `try/catch`
block around this loop. The `sleep()` method in `Thread` might throw an 
`InterruptedException`. This would happen if some other thread wanted to interrupt 
this sleeping one. This example just prints a message if it gets interrupted. In a real 
program, you would need to handle this differently. Here is the output generated by 
this program:

Current thread: Thread[main,5,main]
After name change: Thread[My Thread,5,main]
5
4
3
2
1

Notice the output produced when `t` is used as an argument to `println()`. This 
displays, in order: the name of the thread, its priority, and the name of its group. By 
default, the name of the main thread is `main`. Its priority is 5, which is the default 
value, and `main` is also the name of the group of threads to which this thread 
belongs. A `thread group` is a data structure that controls the state of a collection of 
threads as a whole. After the name of the thread is changed, `t` is again output. This 
time, the new name of the thread is displayed.

Let’s look more closely at the methods defined by `Thread` that are used in the 
program. The `sleep()` method causes the thread from which it is called to suspend 
execution for the specified period of milliseconds. Its general form is shown here:

```java
static void sleep(long milliseconds) throws InterruptedException
```

The number of milliseconds to suspend is specified in `milliseconds`. This method 
may throw an `InterruptedException`.

The `sleep()` method has a second form, shown next, which allows you to specify 
the period in terms of milliseconds and nanoseconds:

```java
static void sleep(long milliseconds, int nanoseconds) throws InterruptedException
```

This second form is useful only in environments that allow timing periods as short as 
nanoseconds.

As the preceding program shows, you can set the name of a thread by using 
`setName()`. You can obtain the name of a thread by calling `getName()` (but note 
that this is not shown in the program). These methods are members of the `Thread` 
class and are declared like this:
void setName(String threadName)
final String getName()

Here, threadName specifies the name of the thread.

Creating a Thread

In the most general sense, you create a thread by instantiating an object of type Thread. Java defines two ways in which this can be accomplished:

- You can implement the Runnable interface.
- You can extend the Thread class, itself.

The following two sections look at each method, in turn.

Implementing Runnable

The easiest way to create a thread is to create a class that implements the Runnable interface. Runnable abstracts a unit of executable code. You can construct a thread on any object that implements Runnable. To implement Runnable, a class need only implement a single method called run(), which is declared like this:

```java
public void run()
```

Inside run(), you will define the code that constitutes the new thread. It is important to understand that run() can call other methods, use other classes, and declare variables, just like the main thread can. The only difference is that run() establishes the entry point for another, concurrent thread of execution within your program. This thread will end when run() returns.

After you create a class that implements Runnable, you will instantiate an object of type Thread from within that class. Thread defines several constructors. The one that we will use is shown here:

```java
Thread(Runnable threadOb, String threadName)
```

In this constructor, threadOb is an instance of a class that implements the Runnable interface. This defines where execution of the thread will begin. The name of the new thread is specified by threadName.

After the new thread is created, it will not start running until you call its start() method, which is declared within Thread. In essence, start() initiates a call to run(). The start() method is shown here:
void start()

Here is an example that creates a new thread and starts it running:

// Create a second thread.
class NewThread implements Runnable {
    Thread t;

    NewThread() {
        // Create a new, second thread
        t = new Thread(this, "Demo Thread");
        System.out.println("Child thread: " + t);
    }

    // This is the entry point for the second thread.
    public void run() {
        try {
            for(int i = 5; i > 0; i--) {
                System.out.println("Child Thread: " + i);
                Thread.sleep(500);
            }
        } catch (InterruptedException e) {
            System.out.println("Child interrupted.");
        }
        System.out.println("Exiting child thread.");
    }
}
Inside NewThread’s constructor, a new Thread object is created by the following statement:

t = new Thread(this, "Demo Thread");

Passing this as the first argument indicates that you want the new thread to call the run() method on this object. Inside main(), start() is called, which starts the thread of execution beginning at the run() method. This causes the child thread’s for loop to begin. Next the main thread enters its for loop. Both threads continue running, sharing the CPU in single-core systems, until their loops finish. The output produced by this program is as follows. (Your output may vary based upon the specific execution environment.)

Child thread: Thread[Demo Thread,5,main]
Main Thread: 5
Child Thread: 5
Child Thread: 4
Main Thread: 4
Child Thread: 3
Child Thread: 2
Main Thread: 3
Child Thread: 1
Exiting child thread.
Main Thread: 2
Main Thread: 1
Main thread exiting.
As mentioned earlier, in a multithreaded program, it is often useful for the main thread to be the last thread to finish running. The preceding program ensures that the main thread finishes last, because the main thread sleeps for 1,000 milliseconds between iterations, but the child thread sleeps for only 500 milliseconds. This causes the child thread to terminate earlier than the main thread. Shortly, you will see a better way to wait for a thread to finish.

**Extending Thread**

The second way to create a thread is to create a new class that extends `Thread`, and then to create an instance of that class. The extending class must override the `run()` method, which is the entry point for the new thread. As before, a call to `start()` begins execution of the new thread. Here is the preceding program rewritten to extend `Thread`: 
// Create a second thread by extending Thread
class NewThread extends Thread {

    NewThread() {
        // Create a new, second thread
        super("Demo Thread");
        System.out.println("Child thread: " + this);
    }

    // This is the entry point for the second thread.
    public void run() {
        try {
            for(int i = 5; i > 0; i--) {
                System.out.println("Child Thread: " + i);
                Thread.sleep(500);
            }
        } catch (InterruptedException e) {
            System.out.println("Child interrupted.");
        }
        System.out.println("Exiting child thread.");
    }
}

class ExtendThread {
    public static void main(String args[]) {
        NewThread nt = new NewThread(); // create a new thread
        nt.start(); // start the thread

        try {
            for(int i = 5; i > 0; i--) {
                System.out.println("Main Thread: " + i);
                Thread.sleep(1000);
            }
        } catch (InterruptedException e) {
            System.out.println("Main thread interrupted.");
        }
        System.out.println("Main thread exiting.");
    }
}

This program generates the same output as the preceding version. As you can see, the child thread is created by instantiating an object of NewThread, which is derived from Thread.
Notice the call to `super()` inside `NewThread`. This invokes the following form of the `Thread` constructor:

```java
public Thread(String threadName)
```

Here, `threadName` specifies the name of the thread.

**Choosing an Approach**

At this point, you might be wondering why Java has two ways to create child threads, and which approach is better. The answers to these questions turn on the same point. The `Thread` class defines several methods that can be overridden by a derived class. Of these methods, the only one that **must** be overridden is `run()`. This is, of course, the same method required when you implement `Runnable`. Many Java programmers feel that classes should be extended only when they are being enhanced or adapted in some way. So, if you will not be overriding any of `Thread`’s other methods, it is probably best simply to implement `Runnable`. Also, by implementing `Runnable`, your thread class does not need to inherit `Thread`, making it free to inherit a different class. Ultimately, which approach to use is up to you. However, throughout the rest of this chapter, we will create threads by using classes that implement `Runnable`.

**Creating Multiple Threads**

So far, you have been using only two threads: the main thread and one child thread. However, your program can spawn as many threads as it needs. For example, the following program creates three child threads:
// Create multiple threads.
class NewThread implements Runnable {
    String name; // name of thread
    Thread t;

    NewThread(String threadname) {
        name = threadname;
        t = new Thread(this, name);
        System.out.println("New thread: " + t);
    }

    // This is the entry point for thread.
    public void run() {
        try {
            for(int i = 5; i > 0; i--) {
                System.out.println(name + ": " + i);
                Thread.sleep(1000);
            }
        } catch (InterruptedException e) {
            System.out.println(name + " Interrupted");
        }
        System.out.println(name + " exiting.");
    }
}
class MultiThreadDemo {
    public static void main(String args[]) {
        NewThread nt1 = new NewThread("One");
        NewThread nt2 = new NewThread("Two");
        NewThread nt3 = new NewThread("Three");

        // Start the threads.
        nt1.t.start();
        nt2.t.start();
        nt3.t.start();

        try {
            // wait for other threads to end
            Thread.sleep(10000);
        } catch (InterruptedException e) {
            System.out.println("Main thread Interrupted");
        }

        System.out.println("Main thread exiting.");
    }
}

Sample output from this program is shown here. (Your output may vary based upon the specific execution environment.)
As you can see, once started, all three child threads share the CPU. Notice the call to `sleep(10000)` in `main()`. This causes the main thread to sleep for ten seconds and ensures that it will finish last.

## Using `isAlive()` and `join()`

As mentioned, often you will want the main thread to finish last. In the preceding examples, this is accomplished by calling `sleep()` within `main()`, with a long enough delay to ensure that all child threads terminate prior to the main thread. However, this is hardly a satisfactory solution, and it also raises a larger question: How can one thread know when another thread has ended? Fortunately, `Thread` provides a means by which you can answer this question.

Two ways exist to determine whether a thread has finished. First, you can call `isAlive()` on the thread. This method is defined by `Thread`, and its general form is shown here:

```
final boolean isAlive()
```

The `isAlive()` method returns `true` if the thread upon which it is called is still...
running. It returns \texttt{false} otherwise.

While \texttt{isAlive()} is occasionally useful, the method that you will more commonly use to wait for a thread to finish is called \texttt{join()}, shown here:

\begin{verbatim}
final void join() throws InterruptedException
\end{verbatim}

This method waits until the thread on which it is called terminates. Its name comes from the concept of the calling thread waiting until the specified thread joins it. Additional forms of \texttt{join()} allow you to specify a maximum amount of time that you want to wait for the specified thread to terminate.

Here is an improved version of the preceding example that uses \texttt{join()} to ensure that the main thread is the last to stop. It also demonstrates the \texttt{isAlive()} method.

\begin{verbatim}
// Using join() to wait for threads to finish.
class NewThread implements Runnable {
    String name; // name of thread
    Thread t;

    NewThread(String threadname) {
        name = threadname;
        t = new Thread(this, name);
        System.out.println("New thread: " + t);
    }

    // This is the entry point for thread.
    public void run() {
        try {
            for(int i = 5; i > 0; i--) {
                System.out.println(name + ": " + i);
                Thread.sleep(1000);
            }
        } catch (InterruptedException e) {
            System.out.println(name + " interrupted.");
        }
        System.out.println(name + " exiting.");
    }
}
\end{verbatim}
class DemoJoin {
    public static void main(String args[]) {
        NewThread nt1 = new NewThread("One");
        NewThread nt2 = new NewThread("Two");
        NewThread nt3 = new NewThread("Three");

        // Start the threads.
        nt1.t.start();
        nt2.t.start();
        nt3.t.start();

        System.out.println("Thread One is alive: 
                           + nt1.t.isAlive());
        System.out.println("Thread Two is alive: 
                           + nt2.t.isAlive());
        System.out.println("Thread Three is alive: 
                           + nt3.t.isAlive());

        // wait for threads to finish
        try {
            System.out.println("Waiting for threads to finish.");
            nt1.t.join();
            nt2.t.join();
            nt3.t.join();
        } catch (InterruptedException e) {
            System.out.println("Main thread Interrupted");
        }

        System.out.println("Thread One is alive: 
                           + nt1.t.isAlive());
        System.out.println("Thread Two is alive: 
                           + nt2.t.isAlive());
        System.out.println("Thread Three is alive: 
                           + nt3.t.isAlive());

        System.out.println("Main thread exiting.");
    }
}

Sample output from this program is shown here. (Your output may vary based upon the specific execution environment.)
New thread: Thread[One,5,main]
New thread: Thread[Two,5,main]
New thread: Thread[Three,5,main]
Thread One is alive: true
Thread Two is alive: true
Thread Three is alive: true
Waiting for threads to finish.
One: 5
Two: 5
Three: 5
One: 4
Two: 4
Three: 4
One: 3
Two: 3
Three: 3
One: 2
Two: 2
Three: 2
One: 1
Two: 1
Three: 1
Two exiting.
Three exiting.
One exiting.
Thread One is alive: false
Thread Two is alive: false
Thread Three is alive: false
Main thread exiting.

As you can see, after the calls to `join()` return, the threads have stopped executing.

Thread Priorities
Thread priorities are used by the thread scheduler to decide when each thread should be allowed to run. In theory, over a given period of time, higher-priority threads get more CPU time than lower-priority threads. In practice, the amount of CPU time that a thread gets often depends on several factors besides its priority. (For example, how an operating system implements multitasking can affect the relative availability of CPU time.) A higher-priority thread can also preempt a lower-priority one. For instance, when a lower-priority thread is running and a higher-priority thread resumes (from sleeping or waiting on I/O, for example), it will preempt the lower-priority thread.
In theory, threads of equal priority should get equal access to the CPU. But you need to be careful. Remember, Java is designed to work in a wide range of environments. Some of those environments implement multitasking fundamentally differently than others. For safety, threads that share the same priority should yield control once in a while. This ensures that all threads have a chance to run under a nonpreemptive operating system. In practice, even in nonpreemptive environments, most threads still get a chance to run, because most threads inevitably encounter some blocking situation, such as waiting for I/O. When this happens, the blocked thread is suspended and other threads can run. But, if you want smooth multithreaded execution, you are better off not relying on this. Also, some types of tasks are CPU-intensive. Such threads dominate the CPU. For these types of threads, you want to yield control occasionally so that other threads can run.

To set a thread’s priority, use the `setPriority()` method, which is a member of `Thread`. This is its general form:

```
final void setPriority(int level)
```

Here, `level` specifies the new priority setting for the calling thread. The value of `level` must be within the range `MIN_PRIORITY` and `MAX_PRIORITY`. Currently, these values are 1 and 10, respectively. To return a thread to default priority, specify `NORM_PRIORITY`, which is currently 5. These priorities are defined as static final variables within `Thread`.

You can obtain the current priority setting by calling the `getPriority()` method of `Thread`, shown here:

```
final int getPriority()
```

Implementations of Java may have radically different behavior when it comes to scheduling. Most of the inconsistencies arise when you have threads that are relying on preemptive behavior, instead of cooperatively giving up CPU time. The safest way to obtain predictable, cross-platform behavior with Java is to use threads that voluntarily give up control of the CPU.

**Synchronization**

When two or more threads need access to a shared resource, they need some way to ensure that the resource will be used by only one thread at a time. The process by which this is achieved is called *synchronization*. As you will see, Java provides unique, language-level support for it.

Key to synchronization is the concept of the monitor. A *monitor* is an object that
is used as a mutually exclusive lock. Only one thread can own a monitor at a given time. When a thread acquires a lock, it is said to have entered the monitor. All other threads attempting to enter the locked monitor will be suspended until the first thread exits the monitor. These other threads are said to be waiting for the monitor. A thread that owns a monitor can reenter the same monitor if it so desires.

You can synchronize your code in either of two ways. Both involve the use of the synchronized keyword, and both are examined here.

**Using Synchronized Methods**

Synchronization is easy in Java, because all objects have their own implicit monitor associated with them. To enter an object’s monitor, just call a method that has been modified with the synchronized keyword. While a thread is inside a synchronized method, all other threads that try to call it (or any other synchronized method) on the same instance have to wait. To exit the monitor and relinquish control of the object to the next waiting thread, the owner of the monitor simply returns from the synchronized method.

To understand the need for synchronization, let’s begin with a simple example that does not use it—but should. The following program has three simple classes. The first one, Callme, has a single method named call(). The call() method takes a String parameter called msg. This method tries to print the msg string inside of square brackets. The interesting thing to notice is that after call() prints the opening bracket and the msg string, it calls Thread.sleep(1000), which pauses the current thread for one second.

The constructor of the next class, Caller, takes a reference to an instance of the Callme class and a String, which are stored in target and msg, respectively. The constructor also creates a new thread that will call this object’s run() method. The run() method of Caller calls the call() method on the target instance of Callme, passing in the msg string. Finally, the Synch class starts by creating a single instance of Callme, and three instances of Caller, each with a unique message string. The same instance of Callme is passed to each Caller.
// This program is not synchronized.
class Callme {
    void call(String msg) {
        System.out.print("[") + msg);
        try {
            Thread.sleep(1000);
        } catch(InterruptedException e) {
            System.out.println("Interrupted");
        }
        System.out.println("]");
    }
}

class Caller implements Runnable {
    String msg;
    Callme target;
    Thread t;

    public Caller(Callme targ, String s) {
        target = targ;
        msg = s;
        t = new Thread(this);
    }

    public void run() {
        target.call(msg);
    }
}
Here is the output produced by this program:

Hello[Synchronized[World]

As you can see, by calling `sleep()`, the `call()` method allows execution to switch to another thread. This results in the mixed-up output of the three message strings. In this program, nothing exists to stop all three threads from calling the same method, on the same object, at the same time. This is known as a race condition, because the three threads are racing each other to complete the method. This example used `sleep()` to make the effects repeatable and obvious. In most situations, a race condition is more subtle and less predictable, because you can’t be sure when the context switch will occur. This can cause a program to run right one time and wrong the next.

To fix the preceding program, you must serialize access to `call()`. That is, you must restrict its access to only one thread at a time. To do this, you simply need to precede `call()`’s definition with the keyword `synchronized`, as shown here:

```java
class Callme {
    synchronized void call(String msg) {
        ...
    }
}
```
This prevents other threads from entering `call()` while another thread is using it. After `synchronized` has been added to `call()`, the output of the program is as follows:

```
[Hello]
[Synchronized]
[World]
```

Any time that you have a method, or group of methods, that manipulates the internal state of an object in a multithreaded situation, you should use the `synchronized` keyword to guard the state from race conditions. Remember, once a thread enters any synchronized method on an instance, no other thread can enter any other synchronized method on the same instance. However, nonsynchronized methods on that instance will continue to be callable.

### The `synchronized` Statement

While creating `synchronized` methods within classes that you create is an easy and effective means of achieving synchronization, it will not work in all cases. To understand why, consider the following. Imagine that you want to synchronize access to objects of a class that was not designed for multithreaded access. That is, the class does not use `synchronized` methods. Further, this class was not created by you, but by a third party, and you do not have access to the source code. Thus, you can’t add `synchronized` to the appropriate methods within the class. How can access to an object of this class be synchronized? Fortunately, the solution to this problem is quite easy: You simply put calls to the methods defined by this class inside a `synchronized` block.

This is the general form of the `synchronized` statement:

```java
synchronized(objRef) {
    // statements to be synchronized
}
```

Here, `objRef` is a reference to the object being synchronized. A synchronized block ensures that a call to a synchronized method that is a member of `objRef`’s class occurs only after the current thread has successfully entered `objRef`’s monitor.

Here is an alternative version of the preceding example, using a synchronized block within the `run()` method:
// This program uses a synchronized block.
class Callme {
    void call(String msg) {
        System.out.print("[");
        try {
            Thread.sleep(1000);
        } catch (InterruptedException e) {
            System.out.println("Interrupted");
        }
        System.out.println("]");
    }
}

class Caller implements Runnable {
    String msg;
    Callme target;
    Thread t;

    public Caller(Callme targ, String s) {
        target = targ;
        msg = s;
        t = new Thread(this);
    }

    // synchronize calls to call()
    public void run() {
        synchronized(target) { // synchronized block
            target.call(msg);
        }
    }
}

class Synch1 {
    public static void main(String args[]) {
        Callme target = new Callme();
        Caller ob1 = new Caller(target, "Hello");
        Caller ob2 = new Caller(target, "Synchronized");
        Caller ob3 = new Caller(target, "World");
    }
}
Here, the call() method is not modified by synchronized. Instead, the synchronized statement is used inside Caller’s run() method. This causes the same correct output as the preceding example, because each thread waits for the prior one to finish before proceeding.

**Interthread Communication**

The preceding examples unconditionally blocked other threads from asynchronous access to certain methods. This use of the implicit monitors in Java objects is powerful, but you can achieve a more subtle level of control through interprocess communication. As you will see, this is especially easy in Java.

As discussed earlier, multithreading replaces event loop programming by dividing your tasks into discrete, logical units. Threads also provide a secondary benefit: they do away with polling. Polling is usually implemented by a loop that is used to check some condition repeatedly. Once the condition is true, appropriate action is taken. This wastes CPU time. For example, consider the classic queuing problem, where one thread is producing some data and another is consuming it. To make the problem more interesting, suppose that the producer has to wait until the consumer is finished before it generates more data. In a polling system, the consumer would waste many CPU cycles while it waited for the producer to produce. Once the producer was finished, it would start polling, wasting more CPU cycles waiting for the consumer to finish, and so on. Clearly, this situation is undesirable.

To avoid polling, Java includes an elegant interprocess communication mechanism via the wait(), notify(), and notifyAll() methods. These methods are implemented as final methods in Object, so all classes have them. All three methods
can be called only from within a synchronized context. Although conceptually advanced from a computer science perspective, the rules for using these methods are actually quite simple:

- **wait( )** tells the calling thread to give up the monitor and go to sleep until some other thread enters the same monitor and calls **notify( )** or **notifyAll( )**.
- **notify( )** wakes up a thread that called **wait( )** on the same object.
- **notifyAll( )** wakes up all the threads that called **wait( )** on the same object. One of the threads will be granted access.

These methods are declared within **Object**, as shown here:

```java
final void wait( ) throws InterruptedException
final void notify( )
final void notifyAll( )
```

Additional forms of **wait( )** exist that allow you to specify a period of time to wait.

Before working through an example that illustrates interthread communication, an important point needs to be made. Although **wait( )** normally waits until **notify( )** or **notifyAll( )** is called, there is a possibility that in very rare cases the waiting thread could be awakened due to a spurious wakeup. In this case, a waiting thread resumes without **notify( )** or **notifyAll( )** having been called. (In essence, the thread resumes for no apparent reason.) Because of this remote possibility, Oracle recommends that calls to **wait( )** should take place within a loop that checks the condition on which the thread is waiting. The following example shows this technique.

Let’s now work through an example that uses **wait( )** and **notify( )**. To begin, consider the following sample program that incorrectly implements a simple form of the producer/consumer problem. It consists of four classes: **Q**, the queue that you’re trying to synchronize; **Producer**, the threaded object that is producing queue entries; **Consumer**, the threaded object that is consuming queue entries; and **PC**, the tiny class that creates the single **Q**, **Producer**, and **Consumer**.
// An incorrect implementation of a producer and consumer.
class Q {
    int n;

    synchronized int get() {
        System.out.println("Got: " + n);
        return n;
    }

    synchronized void put(int n) {
        this.n = n;
        System.out.println("Put: " + n);
    }
}

class Producer implements Runnable {
    Q q;
    Thread t;

    Producer(Q q) {
        this.q = q;
        t = new Thread(this, "Producer");
    }

    public void run() {
        int i = 0;

        while(true) {
            q.put(i++);
        }
    }
}
class Consumer implements Runnable {
    Q q;
    Thread t;

    Consumer(Q q) {
        this.q = q;
        t = new Thread(this, "Consumer");
    }

    public void run() {
        while(true) {
            q.get();
        }
    }
}

class PC {
    public static void main(String args[]) {
        Q q = new Q();
        Producer p = new Producer(q);
        Consumer c = new Consumer(q);

        // Start the threads.
p.t.start();
c.t.start();
        System.out.println("Press Control-C to stop.");
    }
}

Although the put() and get() methods on Q are synchronized, nothing stops the producer from overrunning the consumer, nor will anything stop the consumer from consuming the same queue value twice. Thus, you get the erroneous output shown here (the exact output will vary with processor speed and task load):
As you can see, after the producer put 1, the consumer started and got the same 1 five times in a row. Then, the producer resumed and produced 2 through 7 without letting the consumer have a chance to consume them.

The proper way to write this program in Java is to use `wait()` and `notify()` to signal in both directions, as shown here:

```java
// A correct implementation of a producer and consumer.
class Q {
    int n;
    boolean valueSet = false;

    synchronized int get() {
        while(!valueSet)
            try {
                wait();
            } catch(InterruptedException e) {
                System.out.println("InterruptedException caught");
            }

        System.out.println("Got: "+ n);
        valueSet = false;
        notify();
        return n;
    }
}
```
synchronized void put(int n) {
    while(valueSet)
        try {
            wait();
        } catch(InterruptedException e) {
            System.out.println("InterruptedException caught");
        }
    this.n = n;
    valueSet = true;
    System.out.println("Put: "+n);
    notify();
}

class Producer implements Runnable {
    Q q;
    Thread t;

    Producer(Q q) {
        this.q = q;
        t = new Thread(this, "Producer");
    }

    public void run() {
        int i = 0;
Inside `get()` and `wait()` is called. This causes its execution to suspend until `Producer` notifies you that some data is ready. When this happens, execution inside `get()` resumes. After the data has been obtained, `get()` calls `notify()`. This tells `Producer` that it is okay to put more data in the queue. Inside `put()`, `wait()` suspends execution until `Consumer` has removed the item from the queue. When execution resumes, the next item of data is put in the queue, and `notify()` is called. This tells `Consumer` that it should now remove it.
Here is some output from this program, which shows the clean synchronous behavior:

```
Put: 1
Got: 1
Put: 2
Got: 2
Put: 3
Got: 3
Put: 4
Got: 4
Put: 5
Got: 5
```

**Deadlock**

A special type of error that you need to avoid that relates specifically to multitasking is *deadlock*, which occurs when two threads have a circular dependency on a pair of synchronized objects. For example, suppose one thread enters the monitor on object X and another thread enters the monitor on object Y. If the thread in X tries to call any synchronized method on Y, it will block as expected. However, if the thread in Y, in turn, tries to call any synchronized method on X, the thread waits forever, because to access X, it would have to release its own lock on Y so that the first thread could complete. Deadlock is a difficult error to debug for two reasons:

- In general, it occurs only rarely, when the two threads time-slice in just the right way.
- It may involve more than two threads and two synchronized objects. (That is, deadlock can occur through a more convoluted sequence of events than just described.)

To understand deadlock fully, it is useful to see it in action. The next example creates two classes, A and B, with methods `foo()` and `bar()`, respectively, which pause briefly before trying to call a method in the other class. The main class, named **Deadlock**, creates an A and a B instance, and then calls `deadlockStart()` to start a second thread that sets up the deadlock condition. The `foo()` and `bar()` methods use `sleep()` as a way to force the deadlock condition to occur.
// An example of deadlock.
class A {
    synchronized void foo(B b) {
        String name = Thread.currentThread().getName();
        System.out.println(name + " entered A.foo");

        try {
            Thread.sleep(1000);
        } catch (Exception e) {
            System.out.println("A Interrupted");
        }

        System.out.println(name + " trying to call B.last");
        b.last();
    }

    synchronized void last() {
        System.out.println("Inside A.last");
    }
}

class B {
    synchronized void bar(A a) {
        String name = Thread.currentThread().getName();
        System.out.println(name + " entered B.bar");

        try {
            Thread.sleep(1000);
        } catch (Exception e) {
        }
When you run this program, you will see the output shown here:
MainThread entered A.foo
RacingThread entered B.bar
MainThread trying to call B.last()
RacingThread trying to call A.last()

Because the program has deadlocked, you need to press CTRL-C to end the program. You can see a full thread and monitor cache dump by pressing CTRL-BREAK on a PC. You will see that RacingThread owns the monitor on b, while it is waiting for the monitor on a. At the same time, MainThread owns a and is waiting to get b. This program will never complete. As this example illustrates, if your multithreaded program locks up occasionally, deadlock is one of the first conditions that you should check for.

Suspending, Resuming, and Stopping Threads

Sometimes, suspending execution of a thread is useful. For example, a separate thread can be used to display the time of day. If the user doesn’t want a clock, then its thread can be suspended. Whatever the case, suspending a thread is a simple matter. Once suspended, restarting the thread is also a simple matter.

The mechanisms to suspend, stop, and resume threads differ between early versions of Java, such as Java 1.0, and modern versions, beginning with Java 2. Prior to Java 2, a program used suspend(), resume(), and stop(), which are methods defined by Thread, to pause, restart, and stop the execution of a thread. Although these methods seem to be a perfectly reasonable and convenient approach to managing the execution of threads, they must not be used for new Java programs. Here’s why. The suspend() method of the Thread class was deprecated by Java 2 several years ago. This was done because suspend() can sometimes cause serious system failures. Assume that a thread has obtained locks on critical data structures. If that thread is suspended at that point, those locks are not relinquished. Other threads that may be waiting for those resources can be deadlocked.

The resume() method is also deprecated. It does not cause problems, but cannot be used without the suspend() method as its counterpart.

The stop() method of the Thread class, too, was deprecated by Java 2. This was done because this method can sometimes cause serious system failures. Assume that a thread is writing to a critically important data structure and has completed only part of its changes. If that thread is stopped at that point, that data structure might be left in a corrupted state. The trouble is that stop() causes any lock the calling thread holds to be released. Thus, the corrupted data might be used by another thread that is waiting on the same lock.

Because you can’t now use the suspend(), resume(), or stop() methods to
control a thread, you might be thinking that no way exists to pause, restart, or terminate a thread. But, fortunately, this is not true. Instead, a thread must be designed so that the run() method periodically checks to determine whether that thread should suspend, resume, or stop its own execution. Typically, this is accomplished by establishing a flag variable that indicates the execution state of the thread. As long as this flag is set to “running,” the run() method must continue to let the thread execute. If this variable is set to “suspend,” the thread must pause. If it is set to “stop,” the thread must terminate. Of course, a variety of ways exist in which to write such code, but the central theme will be the same for all programs.

The following example illustrates how the wait() and notify() methods that are inherited from Object can be used to control the execution of a thread. Let us consider its operation. The NewThread class contains a boolean instance variable named suspendFlag, which is used to control the execution of the thread. It is initialized to false by the constructor. The run() method contains a synchronized statement block that checks suspendFlag. If that variable is true, the wait() method is invoked to suspend the execution of the thread. The mysuspend() method sets suspendFlag to true. The myresume() method sets suspendFlag to false and invokes notify() to wake up the thread. Finally, the main() method has been modified to invoke the mysuspend() and myresume() methods.

```java
// Suspending and resuming a thread the modern way.
class NewThread implements Runnable {
    String name; // name of thread
    Thread t;
```
boolean suspendFlag;

NewThread(String threadname) {
    name = threadname;
    t = new Thread(this, name);
    System.out.println("New thread: "+ t);
    suspendFlag = false;
}

// This is the entry point for thread.
public void run() {
    try {
        for(int i = 15; i > 0; i--) {
            System.out.println(name + ": "+ i);
            Thread.sleep(200);
            synchronized(this) {
                while(suspendFlag) {
                    wait();
                }
            }
        }
    } catch (InterruptedException e) {
        System.out.println(name + " interrupted.");
    }
    System.out.println(name + " exiting.");
}
synchronized void mysuspend() {
    suspendFlag = true;
}

synchronized void myresume() {
    suspendFlag = false;
    notify();
}
}

class SuspendResume {
    public static void main(String args[]) {
        NewThread ob1 = new NewThread("One");
        NewThread ob2 = new NewThread("Two");

        ob1.t.start(); // Start the thread
        ob2.t.start(); // Start the thread

        try {
            Thread.sleep(1000);
            ob1.mysuspend();
            System.out.println("Suspending thread One");
            Thread.sleep(1000);
            ob1.myresume();
            System.out.println("Resuming thread One");
            ob2.mysuspend();
            System.out.println("Suspending thread Two");
            Thread.sleep(1000);
        }
    }
}
When you run the program, you will see the threads suspend and resume. Later in this book, you will see more examples that use the modern mechanism of thread control. Although this mechanism isn’t as “clean” as the old way, nevertheless, it is the way required to ensure that run-time errors don’t occur. It is the approach that must be used for all new code.

Obtaining a Thread’s State

As mentioned earlier in this chapter, a thread can exist in a number of different states. You can obtain the current state of a thread by calling the `getState()` method defined by `Thread`. It is shown here:

```java
Thread.State getState()
```

It returns a value of type `Thread.State` that indicates the state of the thread at the time at which the call was made. `State` is an enumeration defined by `Thread`. (An enumeration is a list of named constants. It is discussed in detail in Chapter 12.) Here are the values that can be returned by `getState()`:
<table>
<thead>
<tr>
<th>Value</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLOCKED</td>
<td>A thread that has suspended execution because it is waiting to acquire a lock.</td>
</tr>
<tr>
<td>NEW</td>
<td>A thread that has not begun execution.</td>
</tr>
<tr>
<td>RUNNABLE</td>
<td>A thread that either is currently executing or will execute when it gains access to the CPU.</td>
</tr>
<tr>
<td>TERMINATED</td>
<td>A thread that has completed execution.</td>
</tr>
<tr>
<td>TIMED_WAITING</td>
<td>A thread that has suspended execution for a specified period of time, such as when it has called <code>sleep()</code>. This state is also entered when a timeout version of <code>wait()</code> or <code>join()</code> is called.</td>
</tr>
<tr>
<td>WAITING</td>
<td>A thread that has suspended execution because it is waiting for some action to occur. For example, it is waiting because of a call to a non-timeout version of <code>wait()</code> or <code>join()</code>.</td>
</tr>
</tbody>
</table>

Figure 11-1 diagrams how the various thread states relate.
Given a Thread instance, you can use `getState()` to obtain the state of a thread. For example, the following sequence determines if a thread called `thrd` is in the Runnable state at the time `getState()` is called:

```java
Thread.State ts = thrd.getState();
if (ts == Thread.State.RUNNABLE) // ...
```

It is important to understand that a thread’s state may change after the call to `getState()`. Thus, depending on the circumstances, the state obtained by calling `getState()` may not reflect the actual state of the thread only a moment later. For this (and other) reasons, `getState()` is not intended to provide a means of synchronizing threads. It’s primarily used for debugging or for profiling a thread’s run-time characteristics.
Using a Factory Method to Create and Start a Thread

In some cases, it is not necessary to separate the creation of a thread from the start of its execution. In other words, sometimes it is convenient to create and start a thread at the same time. One way to do this is to use a static factory method. A *factory method* is a method that returns an object of a class. Typically, factory methods are *static* methods of a class. They are used for a variety of reasons, such as to set an object to some initial state prior to use, to configure a specific type of object, or in some cases to enable an object to be reused. As it relates to creating and starting a thread, a factory method will create the thread, call `start()` on the thread, and then return a reference to the thread. With this approach, you can create and start a thread through a single method call, thus streamlining your code.

For example, assuming the `ThreadDemo` program shown near the start of this chapter, adding the following factory method to `NewThread` enables you to create and start a thread in a single step:

```java
// A factory method that creates and starts a thread.
public static NewThread createAndStart() {
    NewThread myThrd = new NewThread();
    myThrd.t.start();
    return myThrd;
}
```

Using `createAndStart()`, you can now replace this sequence:

```java
NewThread nt = new NewThread(); // create a new thread
nt.t.start(); // Start the thread
```

with

```java
NewThread nt = NewThread.createAndStart();
```

Now the thread is created and started in one step.

In cases in which you don’t need to keep a reference to the executing thread, you can sometimes create and start a thread with one line of code, without the use of a factory method. For example, again assuming the `ThreadDemo` program, the following creates and starts a `NewThread` thread:

```java
new NewThread().t.start();
```

However, in real-world applications, you will usually need to keep a reference to the
thread, so the factory method is often a good choice.

Using Multithreading

The key to utilizing Java’s multithreading features effectively is to think concurrently rather than serially. For example, when you have two subsystems within a program that can execute concurrently, make them individual threads. With the careful use of multithreading, you can create very efficient programs. A word of caution is in order, however: If you create too many threads, you can actually degrade the performance of your program rather than enhance it. Remember, some overhead is associated with context switching. If you create too many threads, more CPU time will be spent changing contexts than executing your program! One last point: To create compute-intensive applications that can automatically scale to make use of the available processors in a multi-core system, consider using the Fork/Join Framework, which is described in Chapter 28.
CHAPTER
This chapter examines three features that were not originally part of Java, but over time each has become a near indispensable aspect of Java programming: enumerations, autoboxing, and annotations. Added by JDK 5, each is a feature upon which Java programmers have come to rely because each offers a streamlined approach to handling common programming tasks. This chapter also discusses Java’s type wrappers and introduces reflection.

Enumerations

In its simplest form, an enumeration is a list of named constants that define a new data type and its legal values. Thus, an enumeration object can hold only a value that was declared in the list. Other values are not allowed. In other words, an enumeration gives you a way to explicitly specify the only values that a data type can legally have. Enumerations are commonly used to define a set of values that represent a collection of items. For example, you might use an enumeration to represent the error codes that can result from some operation, such as success, failed, or pending; or a list of the states that a device might be in, such as running, stopped, or paused. In early versions of Java, such values were defined using final variables, but enumerations offer a far superior approach.

Although Java enumerations might, at first glance, appear similar to enumerations in other languages, this similarity may be only skin deep because, in Java, an enumeration defines a class type. By making enumerations into classes, the capabilities of the enumeration are greatly expanded. For example, in Java, an enumeration can have constructors, methods, and instance variables. Because of their power and flexibility, enumerations are widely used throughout the Java API library.

Enumeration Fundamentals

An enumeration is created using the enum keyword. For example, here is a simple enumeration that lists various apple varieties:
// An enumeration of apple varieties.
enum Apple {
    Jonathan, GoldenDel, RedDel, Winesap, Cortland
}

The identifiers Jonathan, GoldenDel, and so on, are called enumeration constants. Each is implicitly declared as a public, static final member of Apple. Furthermore, their type is the type of the enumeration in which they are declared, which is Apple in this case. Thus, in the language of Java, these constants are called self-typed, in which “self” refers to the enclosing enumeration.

Once you have defined an enumeration, you can create a variable of that type. However, even though enumerations define a class type, you do not instantiate an enum using new. Instead, you declare and use an enumeration variable in much the same way as you do one of the primitive types. For example, this declares ap as a variable of enumeration type Apple:

Apple ap;

Because ap is of type Apple, the only values that it can be assigned (or can contain) are those defined by the enumeration. For example, this assigns ap the value RedDel:

ap = Apple.RedDel;

Notice that the symbol RedDel is preceded by Apple.

Two enumeration constants can be compared for equality by using the == relational operator. For example, this statement compares the value in ap with the GoldenDel constant:

if(ap == Apple.GoldenDel) // ...  

An enumeration value can also be used to control a switch statement. Of course, all of the case statements must use constants from the same enum as that used by the switch expression. For example, this switch is perfectly valid:

// Use an enum to control a switch statement.
switch(ap) {
    case Jonathan:
        // ...
    case Winesap:
        // ...
}

Notice that in the case statements, the names of the enumeration constants are used
without being qualified by their enumeration type name. That is, Winesap, not Apple.Winesap, is used. This is because the type of the enumeration in the switch expression has already implicitly specified the enum type of the case constants. There is no need to qualify the constants in the case statements with their enum type name. In fact, attempting to do so will cause a compilation error.

When an enumeration constant is displayed, such as in a println() statement, its name is output. For example, given this statement:

System.out.println(Apple.Winesap);

the name Winesap is displayed.

The following program puts together all of the pieces and demonstrates the Apple enumeration:

```java
// An enumeration of apple varieties.
enum Apple {
    Jonathan, GoldenDel, RedDel, Winesap, Cortland
}

class EnumDemo {
    public static void main(String args[]) {
        Apple ap;

        ap = Apple.RedDel;

        // Output an enum value.
        System.out.println("Value of ap: " + ap);
        System.out.println();

        ap = Apple.GoldenDel;

        // Compare two enum values.
        if(ap == Apple.GoldenDel) {
            System.out.println("ap contains GoldenDel.\n");
        }
    }
}
```
The output from the program is shown here:

Value of ap: RedDel

ap contains GoldenDel.

Golden Delicious is yellow.

The values( ) and valueOf( ) Methods

All enumerations automatically contain two predefined methods: values() and valueOf(). Their general forms are shown here:

```
public static enum-type [ ] values()
public static enum-type valueOf(String str)
```

The values( ) method returns an array that contains a list of the enumeration constants. The valueOf( ) method returns the enumeration constant whose value corresponds to the string passed in str. In both cases, enum-type is the type of the enumeration. For example, in the case of the Apple enumeration shown earlier, the return type of Apple.valueOf("Winesap") is Winesap.

The following program demonstrates the values( ) and valueOf( ) methods:
The output from the program is shown here:

Here are all Apple constants:
Jonathan
GoldenDel
RedDel
Winesap
Cortland

ap contains Winesap

Notice that this program uses a for-each style `for` loop to cycle through the array of constants obtained by calling `values()`. For the sake of illustration, the variable `allapples` was created and assigned a reference to the enumeration array. However, this step is not necessary because the `for` could have been written as shown here, eliminating the need for the `allapples` variable:
Now, notice how the value corresponding to the name Winesap was obtained by calling `valueOf()`.

```java
ap = Apple.valueOf("Winesap");
```

As explained, `valueOf()` returns the enumeration value associated with the name of the constant represented as a string.

**Java Enumerations Are Class Types**

As mentioned, a Java enumeration is a class type. Although you don’t instantiate an `enum` using `new`, it otherwise has much the same capabilities as other classes. The fact that `enum` defines a class gives the Java enumeration extraordinary power. For example, you can give them constructors, add instance variables and methods, and even implement interfaces.

It is important to understand that each enumeration constant is an object of its enumeration type. Thus, when you define a constructor for an `enum`, the constructor is called when each enumeration constant is created. Also, each enumeration constant has its own copy of any instance variables defined by the enumeration. For example, consider the following version of `Apple`:

```java
// Use an enum constructor, instance variable, and method.
enum Apple {
    Jonathan(10), GoldenDel(9), RedDel(12), Winesap(15), Cortland(8);

    private int price; // price of each apple

    // Constructor
    Apple(int p) { price = p; }

    int getPrice() { return price; }
}
```
class EnumDemo3 {
    public static void main(String args[])
    {
        Apple ap;

        // Display price of Winesap.
        System.out.println("Winesap costs "+
            Apple.Winesap.getPrice() +
            " cents.\n");

        // Display all apples and prices.
        System.out.println("All apple prices:");
        for(Apple a : Apple.values())
            System.out.println(a + " costs " + a.getPrice() +
            " cents.");
    }
}

The output is shown here:

Winesap costs 15 cents.

All apple prices:
Jonathan costs 10 cents.
GoldenDel costs 9 cents.
RedDel costs 12 cents.
Winesap costs 15 cents.
Cortland costs 8 cents.

This version of Apple adds three things. The first is the instance variable price, which is used to hold the price of each variety of apple. The second is the Apple constructor, which is passed the price of an apple. The third is the method getPrice(), which returns the value of price.

When the variable ap is declared in main(), the constructor for Apple is called once for each constant that is specified. Notice how the arguments to the constructor are specified, by putting them inside parentheses after each constant, as shown here:

Jonathan(10), GoldenDel(9), RedDel(12), Winesap(15), Cortland(8);

These values are passed to the p parameter of Apple(), which then assigns this value to price. Again, the constructor is called once for each constant.

Because each enumeration constant has its own copy of price, you can obtain the price of a specified type of apple by calling getPrice(). For example, in main() the price of a Winesap is obtained by the following call:
The prices of all varieties are obtained by cycling through the enumeration using a for loop. Because there is a copy of price for each enumeration constant, the value associated with one constant is separate and distinct from the value associated with another constant. This is a powerful concept, which is only available when enumerations are implemented as classes, as Java does.

Although the preceding example contains only one constructor, an enum can offer two or more overloaded forms, just as can any other class. For example, this version of Apple provides a default constructor that initializes the price to –1, to indicate that no price data is available:

```java
// Use an enum constructor.
enum Apple {
    Jonathan(10), GoldenDel(9), RedDel, Winesap(15), Cortland(8);

    private int price; // price of each apple

    // Constructor
    Apple(int p) { price = p; }

    // Overloaded constructor
    Apple() { price = -1; }

    int getPrice() { return price; }
}
```

Notice that in this version, RedDel is not given an argument. This means that the default constructor is called, and RedDel’s price variable is given the value –1.

Here are two restrictions that apply to enumerations. First, an enumeration can’t inherit another class. Second, an enum cannot be a superclass. This means that an enum can’t be extended. Otherwise, enum acts much like any other class type. The key is to remember that each of the enumeration constants is an object of the class in which it is defined.

**Enumerations Inherit Enum**

Although you can’t inherit a superclass when declaring an enum, all enumerations automatically inherit one: `java.lang.Enum`. This class defines several methods that are available for use by all enumerations. The Enum class is described in detail in *Part II*, but three of its methods warrant a discussion at this time.

You can obtain a value that indicates an enumeration constant’s position in the
list of constants. This is called its *ordinal value*, and it is retrieved by calling the \texttt{ordinal()} method, shown here:

```java
definal\ int\ ordinal()
```

It returns the ordinal value of the invoking constant. Ordinal values begin at zero. Thus, in the \texttt{Apple} enumeration, \texttt{Jonathan} has an ordinal value of zero, \texttt{GoldenDel} has an ordinal value of 1, \texttt{RedDel} has an ordinal value of 2, and so on.

You can compare the ordinal value of two constants of the same enumeration by using the \texttt{compareTo()} method. It has this general form:

```java
definal\ int\ compareTo(enum-type\ e)
```

Here, \textit{enum-type} is the type of the enumeration, and \texttt{e} is the constant being compared to the invoking constant. Remember, both the invoking constant and \texttt{e} must be of the same enumeration. If the invoking constant has an ordinal value less than \texttt{e}’s, then \texttt{compareTo()} returns a negative value. If the two ordinal values are the same, then zero is returned. If the invoking constant has an ordinal value greater than \texttt{e}’s, then a positive value is returned.

You can compare for equality an enumeration constant with any other object by using \texttt{equals()}, which overrides the \texttt{equals()} method defined by \texttt{Object}. Although \texttt{equals()} can compare an enumeration constant to any other object, those two objects will be equal only if they both refer to the same constant, within the same enumeration. Simply having ordinal values in common will not cause \texttt{equals()} to return true if the two constants are from different enumerations.

Remember, you can compare two enumeration references for equality by using \texttt{=}.\texttt{=}

The following program demonstrates the \texttt{ordinal()}, \texttt{compareTo()}, and \texttt{equals()} methods:
// Demonstrate ordinal(), compareTo(), and equals().

// An enumeration of apple varieties.
enum Apple {
    Jonathan, GoldenDel, RedDel, Winesap, Cortland
}

class EnumDemo4 {
    public static void main(String args[])
    {
        Apple ap, ap2, ap3;

        // Obtain all ordinal values using ordinal().
        System.out.println("Here are all apple constants" +
                            " and their ordinal values: ");
        for(Apple a : Apple.values())
            System.out.println(a + " " + a.ordinal());

        ap = Apple.RedDel;
        ap2 = Apple.GoldenDel;
        ap3 = Apple.RedDel;

        System.out.println();

        // Demonstrate compareTo() and equals()
        if(ap.compareTo(ap2) < 0)
            System.out.println(ap + " comes before " + ap2);

        if(ap.compareTo(ap2) > 0)
            System.out.println(ap2 + " comes before " + ap);

        if(ap.compareTo(ap3) == 0)
            System.out.println(ap + " equals " + ap3);

        System.out.println();

        if(ap.equals(ap2))
            System.out.println("Error!");

        if(ap.equals(ap3))
            System.out.println(ap + " equals " + ap3);
Another Enumeration Example

Before moving on, we will look at a different example that uses an `enum`. In Chapter 9, an automated “decision maker” program was created. In that version, variables called `NO`, `YES`, `MAYBE`, `LATER`, `SOON`, and `NEVER` were declared within an interface and used to represent the possible answers. While there is nothing technically wrong with that approach, the enumeration is a better choice. Here is an improved version of that program that uses an `enum` called `Answers` to define the answers. You should compare this version to the original in Chapter 9.
// An improved version of the "Decision Maker"
// program from Chapter 9. This version uses an
// enum, rather than interface variables, to
// represent the answers.

import java.util.Random;

// An enumeration of the possible answers.
enum Answers {
    NO, YES, MAYBE, LATER, SOON, NEVER
}

class Question {
    Random rand = new Random();
    Answers ask() {
        int prob = (int) (100 * rand.nextDouble());

        if (prob < 15)
            return Answers.MAYBE; // 15%
        else if (prob < 30)
            return Answers.NO; // 15%
        else if (prob < 60)
            return Answers.YES; // 30%
    }
}
else if (prob < 75)
    return Answers.LATER; // 15%
else if (prob < 98)
    return Answers.SOON; // 13%
else
    return Answers.NEVER; // 2%
}

class AskMe {
    static void answer(Answers result) {
        switch(result) {
            case NO:
                System.out.println("No");
                break;
            case YES:
                System.out.println("Yes");
                break;
            case MAYBE:
                System.out.println("Maybe");
                break;
            case LATER:
                System.out.println("Later");
                break;
            case SOON:
                System.out.println("Soon");
                break;
            case NEVER:
                System.out.println("Never");
                break;
        }
    }
}

public static void main(String args[]) {
    Question q = new Question();
    answer(q.ask());
    answer(q.ask());
    answer(q.ask());
    answer(q.ask());
    answer(q.ask());
}

Type Wrappers

As you know, Java uses primitive types (also called simple types), such as `int` or `double`, to hold the basic data types supported by the language. Primitive types, rather than objects, are used for these quantities for the sake of performance. Using objects for these values would add an unacceptable overhead to even the simplest of calculations. Thus, the primitive types are not part of the object hierarchy, and they do not inherit `Object`.

Despite the performance benefit offered by the primitive types, there are times when you will need an object representation. For example, you can’t pass a primitive type by reference to a method. Also, many of the standard data structures implemented by Java operate on objects, which means that you can’t use these data structures to store primitive types. To handle these (and other) situations, Java provides type wrappers, which are classes that encapsulate a primitive type within an object. The type wrapper classes are described in detail in Part II, but they are introduced here because they relate directly to Java’s autoboxing feature.

The type wrappers are `Double`, `Float`, `Long`, `Integer`, `Short`, `Byte`, `Character`, and `Boolean`. These classes offer a wide array of methods that allow you to fully integrate the primitive types into Java’s object hierarchy. Each is briefly examined next.

**Character**

`Character` is a wrapper around a `char`. The constructor for `Character` is

```
Character(char ch)
```

Here, `ch` specifies the character that will be wrapped by the `Character` object being created.

However, beginning with JDK 9, the `Character` constructor has been deprecated. Today, it is recommended that you use the static method `valueOf( )` to obtain a `Character` object. It is shown here:

```
static Character valueOf(char ch)
```

It returns a `Character` object that wraps `ch`.

To obtain the `char` value contained in a `Character` object, call `charValue( )`, shown here:

```
char charValue( )
```
It returns the encapsulated character.

**Boolean**

*Boolean* is a wrapper around *boolean* values. It defines these constructors:

- Boolean(boolean *boolValue*)
- Boolean(String *boolString*)

In the first version, *boolValue* must be either *true* or *false*. In the second version, if *boolString* contains the string "true" (in uppercase or lowercase), then the new *Boolean* object will be true. Otherwise, it will be false.

However, beginning with JDK 9, the *Boolean* constructors have been deprecated. Today, it is recommended that you use the static method `valueOf()` to obtain a *Boolean* object. It has the two versions shown here:

- static Boolean `valueOf(boolean *boolValue*)`
- static Boolean `valueOf(String *boolString*)`

Each returns a *Boolean* object that wraps the indicated value.

To obtain a *boolean* value from a *Boolean* object, use `booleanValue()`, shown here:

    boolean booleanValue( )

It returns the *boolean* equivalent of the invoking object.

**The Numeric Type Wrappers**

By far, the most commonly used type wrappers are those that represent numeric values. These are *Byte, Short, Integer, Long, Float, and Double*. All of the numeric type wrappers inherit the abstract class *Number*. *Number* declares methods that return the value of an object in each of the different number formats. These methods are shown here:

    byte byteValue( )
    double doubleValue( )
    float floatValue( )
    int intValue( )
    long longValue( )
short shortValue( )

For example, doubleValue( ) returns the value of an object as a double, floatValue( ) returns the value as a float, and so on. These methods are implemented by each of the numeric type wrappers.

All of the numeric type wrappers define constructors that allow an object to be constructed from a given value, or a string representation of that value. For example, here are the constructors defined for Integer:

   Integer(int num)
   Integer(String str)

If str does not contain a valid numeric value, then a NumberFormatException is thrown.

However, beginning with JDK 9, the numeric type-wrapper constructors have been deprecated. Today, it is recommended that you use one of the valueOf( ) methods to obtain a wrapper object. The valueOf( ) method is a static member of all of the numeric wrapper classes and all numeric classes support forms that convert a numeric value or a string into an object. For example, here are two of the forms supported by Integer:

   static Integer valueOf(int val)
   static Integer valueOf(String valStr) throws NumberFormatException

Here, val specifies an integer value and valStr specifies a string that represents a properly formatted numeric value in string form. Each returns an Integer object that wraps the specified value. Here is an example:

   Integer iOb = Integer.valueOf(100);

After this statement executes, the value 100 is represented by an Integer instance. Thus, iOb wraps the value 100 within an object. In addition to the forms valueOf( ) just shown, the integer wrappers, Byte, Short, Integer, and Long, also supply a form that lets you specify a radix.

All of the type wrappers override toString( ). It returns the human-readable form of the value contained within the wrapper. This allows you to output the value by passing a type wrapper object to println( ), for example, without having to convert it into its primitive type.

The following program demonstrates how to use a numeric type wrapper to encapsulate a value and then extract that value.
This program wraps the integer value 100 inside an \texttt{Integer} object called \texttt{iOb}. The program then obtains this value by calling \texttt{intValue()} and stores the result in \texttt{i}.

The process of encapsulating a value within an object is called \textit{boxing}. Thus, in the program, this line boxes the value 100 into an \texttt{Integer}:

\begin{verbatim}
Integer iOb = Integer.valueOf(100);
\end{verbatim}

The process of extracting a value from a type wrapper is called \textit{unboxing}. For example, the program unboxes the value in \texttt{iOb} with this statement:

\begin{verbatim}
int i = iOb.intValue();
\end{verbatim}

The same general procedure used by the preceding program to box and unbox values has been employed since the original version of Java. However, since JDK 5, Java fundamentally improved on this through the addition of autoboxing, described next.

\section*{Autoboxing}

Beginning with JDK 5, Java has included two important features: \textit{autoboxing} and \textit{auto-unboxing}. Autoboxing is the process by which a primitive type is automatically encapsulated (boxed) into its equivalent type wrapper whenever an object of that type is needed. There is no need to explicitly construct an object. Auto-unboxing is the process by which the value of a boxed object is automatically extracted (unboxed) from a type wrapper when its value is needed. There is no need to call a method such as \texttt{intValue()} or \texttt{doubleValue()}.

Autoboxing and auto-unboxing greatly streamline the coding of several algorithms, removing the tedium of manually boxing and unboxing values. They also help prevent errors. Moreover, they are very important to generics, which operate only on objects. Finally, autoboxing makes working with the Collections Framework (described in Part II) much easier.
With autoboxing, it is not necessary to manually construct an object in order to wrap a primitive type. You need only assign that value to a type-wrapper reference. Java automatically constructs the object for you. For example, here is the modern way to construct an `Integer` object that has the value 100:

```java
Integer iOb = 100; // autobox an int
```

Notice that the object is not explicitly boxed. Java handles this for you, automatically.

To unbox an object, simply assign that object reference to a primitive-type variable. For example, to unbox `iOb`, you can use this line:

```java
int i = iOb; // auto-unbox
```

Java handles the details for you.

Here is the preceding program rewritten to use autoboxing/unboxing:

```java
// Demonstrate autoboxing/unboxing.
class AutoBox {
    public static void main(String args[]) {
        Integer iOb = 100; // autobox an int
        int i = iOb; // auto-unbox
        System.out.println(i + " " + iOb); // displays 100 100
    }
}
```

### Autoboxing and Methods

In addition to the simple case of assignments, autoboxing automatically occurs whenever a primitive type must be converted into an object; auto-unboxing takes place whenever an object must be converted into a primitive type. Thus, autoboxing/unboxing might occur when an argument is passed to a method, or when a value is returned by a method. For example, consider this:
This program displays the following result:

In the program, notice that \texttt{m()} specifies an \texttt{Integer} parameter and returns an \texttt{int} result. Inside \texttt{main()}, \texttt{m()} is passed the value 100. Because \texttt{m()} is expecting an \texttt{Integer}, this value is automatically boxed. Then, \texttt{m()} returns the \texttt{int} equivalent of its argument. This causes \texttt{v} to be auto-unboxed. Next, this \texttt{int} value is assigned to \texttt{iOb} in \texttt{main()}, which causes the \texttt{int} return value to be autoboxed.

**Autoboxing/Unboxing Occurs in Expressions**

In general, autoboxing and unboxing take place whenever a conversion into an object or from an object is required. This applies to expressions. Within an expression, a numeric object is automatically unboxed. The outcome of the expression is reboxed, if necessary. For example, consider the following program:
In the program, pay special attention to this line:

```java
++iOb;
```

This causes the value in `iOb` to be incremented. It works like this: `iOb` is unboxed, the value is incremented, and the result is reboxed.

Auto-unboxing also allows you to mix different types of numeric objects in an
expression. Once the values are unboxed, the standard type promotions and conversions are applied. For example, the following program is perfectly valid:

class AutoBox4 {
    public static void main(String args[]) {

        Integer iOb = 100;
        Double dOb = 98.6;

        dOb = dOb + iOb;
        System.out.println("dOb after expression: " + dOb);
    }
}

The output is shown here:

dOb after expression: 198.6

As you can see, both the Double object dOb and the Integer object iOb participated in the addition, and the result was reboxed and stored in dOb.

Because of auto-unboxing, you can use Integer numeric objects to control a switch statement. For example, consider this fragment:

Integer iOb = 2;

switch(iOb) {
    case 1: System.out.println("one");
            break;
    case 2: System.out.println("two");
            break;
    default: System.out.println("error");
}

When the switch expression is evaluated, iOb is unboxed and its int value is obtained.

As the examples in the programs show, because of autoboxing/unboxing, using numeric objects in an expression is both intuitive and easy. In the past, such code would have involved casts and calls to methods such as intValue().

**Autoboxing/Unboxing Boolean and Character Values**

As described earlier, Java also supplies wrappers for boolean and char. These are Boolean and Character. Autoboxing/unboxing applies to these wrappers, too. For
example, consider the following program:

```java
// Autoboxing/unboxing a Boolean and Character.

class AutoBox5 {
    public static void main(String args[]) {

        // Autobox/unbox a boolean.
        Boolean b = true;

        // Below, b is auto-unboxed when used in
        // a conditional expression, such as an if.
        if(b) System.out.println("b is true");

        // Autobox/unbox a char.
        Character ch = 'x'; // box a char
        char ch2 = ch; // unbox a char

        System.out.println("ch2 is " + ch2);
    }
}
```

The output is shown here:

```
b is true
ch2 is x
```

The most important thing to notice about this program is the auto-unboxing of `b` inside the `if` conditional expression. As you should recall, the conditional expression that controls an `if` must evaluate to type `boolean`. Because of auto-unboxing, the `boolean` value contained within `b` is automatically unboxed when the conditional expression is evaluated. Thus, with autoboxing/unboxing, a `Boolean` object can be used to control an `if` statement.

Because of auto-unboxing, a `Boolean` object can now also be used to control any of Java’s loop statements. When a `Boolean` is used as the conditional expression of a `while`, `for`, or `do/while`, it is automatically unboxed into its `boolean` equivalent. For example, this is perfectly valid code:

```java
Boolean b;
// ...
while(b) { // ...
```

**Autoboxing/Unboxing Helps Prevent Errors**
In addition to the convenience that it offers, autoboxing/unboxing can also help prevent errors. For example, consider the following program:

```java
// An error produced by manual unboxing.
class UnboxingError {
    public static void main(String args[]) {
        Integer iOb = 1000; // autobox the value 1000
        int i = iOb.byteValue(); // manually unbox as byte !!!
        System.out.println(i); // does not display 1000 !
    }
}
```

This program displays not the expected value of 1000, but –24! The reason is that the value inside `iOb` is manually unboxed by calling `byteValue()`, which causes the truncation of the value stored in `iOb`, which is 1,000. This results in the garbage value of –24 being assigned to `i`. Auto-unboxing prevents this type of error because the value in `iOb` will always auto-unbox into a value compatible with `int`.

In general, because autoboxing always creates the proper object, and auto-unboxing always produces the proper value, there is no way for the process to produce the wrong type of object or value. In the rare instances where you want a type different than that produced by the automated process, you can still manually box and unbox values. Of course, the benefits of autoboxing/unboxing are lost. In general, new code should employ autoboxing/unboxing. It is the way that modern Java code is written.

**A Word of Warning**

Because of autoboxing and auto-unboxing, some might be tempted to use objects such as `Integer` or `Double` exclusively, abandoning primitives altogether. For example, with autoboxing/unboxing it is possible to write code like this:
In this example, objects of type Double hold values that are used to calculate the hypotenuse of a right triangle. Although this code is technically correct and does, in fact, work properly, it is a very bad use of autoboxing/unboxing. It is far less efficient than the equivalent code written using the primitive type double. The reason is that each autobox and auto-unbox adds overhead that is not present if the primitive type is used.

In general, you should restrict your use of the type wrappers to only those cases in which an object representation of a primitive type is required. Autoboxing/unboxing was not added to Java as a “back door” way of eliminating the primitive types.

Annotations

Java provides a feature that enables you to embed supplemental information into a source file. This information, called an annotation, does not change the actions of a program. Thus, an annotation leaves the semantics of a program unchanged. However, this information can be used by various tools during both development and deployment. For example, an annotation might be processed by a source-code generator. The term metadata is also used to refer to this feature, but the term annotation is the most descriptive and more commonly used.

Annotation Basics

An annotation is created through a mechanism based on the interface. Let’s begin with an example. Here is the declaration for an annotation called MyAnno:

```java
// A simple annotation type.
@interface MyAnno {
    String str();
    int val();
}
```

First, notice the @ that precedes the keyword interface. This tells the compiler
that an annotation type is being declared. Next, notice the two members `str()` and `val()`. All annotations consist solely of method declarations. However, you don’t provide bodies for these methods. Instead, Java implements these methods. Moreover, the methods act much like fields, as you will see.

An annotation cannot include an `extends` clause. However, all annotation types automatically extend the `Annotation` interface. Thus, `Annotation` is a superinterface of all annotations. It is declared within the `java.lang.annotation` package. It overrides `hashCode()`, `equals()`, and `toString()`, which are defined by `Object`. It also specifies `annotationType()`, which returns a `Class` object that represents the invoking annotation.

Once you have declared an annotation, you can use it to annotate something. Prior to JDK 8, annotations could be used only on declarations, and that is where we will begin. (JDK 8 added the ability to annotate type use, and this is described later in this chapter. However, the same basic techniques apply to both kinds of annotations.) Any type of declaration can have an annotation associated with it. For example, classes, methods, fields, parameters, and `enum` constants can be annotated. Even an annotation can be annotated. In all cases, the annotation precedes the rest of the declaration.

When you apply an annotation, you give values to its members. For example, here is an example of `MyAnno` being applied to a method declaration:

```java
// Annotate a method.
@MyAnno(str = "Annotation Example", val = 100)
public static void myMeth() { // ...

This annotation is linked with the method `myMeth()`. Look closely at the annotation syntax. The name of the annotation, preceded by an @, is followed by a parenthesized list of member initializations. To give a member a value, that member’s name is assigned a value. Therefore, in the example, the string "Annotation Example" is assigned to the `str` member of `MyAnno`. Notice that no parentheses follow `str` in this assignment. When an annotation member is given a value, only its name is used. Thus, annotation members look like fields in this context.

**Specifying a Retention Policy**

Before exploring annotations further, it is necessary to discuss `annotation retention policies`. A retention policy determines at what point an annotation is discarded. Java defines three such policies, which are encapsulated within the `java.lang.annotation.RetentionPolicy` enumeration. They are `SOURCE`, `CLASS`,
and **RUNTIME**.

An annotation with a retention policy of **SOURCE** is retained only in the source file and is discarded during compilation.

An annotation with a retention policy of **CLASS** is stored in the `.class` file during compilation. However, it is not available through the JVM during run time.

An annotation with a retention policy of **RUNTIME** is stored in the `.class` file during compilation and is available through the JVM during run time. Thus, **RUNTIME** retention offers the greatest annotation persistence.

**NOTE** An annotation on a local variable declaration is not retained in the `.class` file.

A retention policy is specified for an annotation by using one of Java’s built-in annotations: `@Retention`. Its general form is shown here:

```
@Retention(retention-policy)
```

Here, `retention-policy` must be one of the previously discussed enumeration constants. If no retention policy is specified for an annotation, then the default policy of **CLASS** is used.

The following version of `MyAnno` uses `@Retention` to specify the **RUNTIME** retention policy. Thus, `MyAnno` will be available to the JVM during program execution.

```
@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
    String str();
    int val();
}
```

**Obtaining Annotations at Run Time by Use of Reflection**

Although annotations are designed mostly for use by other development or deployment tools, if they specify a retention policy of **RUNTIME**, then they can be queried at run time by any Java program through the use of reflection. Reflection is the feature that enables information about a class to be obtained at run time. The reflection API is contained in the `java.lang.reflect` package. There are a number of ways to use reflection, and we won’t examine them all here. We will, however, walk through a few examples that apply to annotations.

The first step to using reflection is to obtain a `Class` object that represents the class whose annotations you want to obtain. `Class` is one of Java’s built-in classes and is defined in `java.lang`. It is described in detail in **Part II**. There are various ways
to obtain a **Class** object. One of the easiest is to call **getClass()**, which is a method defined by **Object**. Its general form is shown here:

```java
final Class<?> getClass()
```

It returns the **Class** object that represents the invoking object.

---

**NOTE** Notice the `<?>` that follows **Class** in the declaration of **getClass()** just shown. This is related to Java’s generics feature. **getClass()** and several other reflection-related methods discussed in this chapter make use of generics. Generics are described in Chapter 14. However, an understanding of generics is not needed to grasp the fundamental principles of reflection.

After you have obtained a **Class** object, you can use its methods to obtain information about the various items declared by the class, including its annotations. If you want to obtain the annotations associated with a specific item declared within a class, you must first obtain an object that represents that item. For example, **Class** supplies (among others) the **getMethod()**, **getField()**, and **getConstructor()** methods, which obtain information about a method, field, and constructor, respectively. These methods return objects of type **Method**, **Field**, and **Constructor**.

To understand the process, let’s work through an example that obtains the annotations associated with a method. To do this, you first obtain a **Class** object that represents the class, and then call **getMethod()** on that **Class** object, specifying the name of the method. **getMethod()** has this general form:

```java
Method getMethod(String methName, Class<?> … paramTypes)
```

The name of the method is passed in `methName`. If the method has arguments, then **Class** objects representing those types must also be specified by `paramTypes`. Notice that `paramTypes` is a varargs parameter. This means that you can specify as many parameter types as needed, including zero. **getMethod()** returns a **Method** object that represents the method. If the method can’t be found, **NoSuchMethodException** is thrown.

From a **Class**, **Method**, **Field**, or **Constructor** object, you can obtain a specific annotation associated with that object by calling **getAnnotation()**. Its general form is shown here:

```java
<A extends Annotation> getAnnotation(Class<A> annoType)
```

Here, `annoType` is a **Class** object that represents the annotation in which you are interested. The method returns a reference to the annotation. Using this reference,
you can obtain the values associated with the annotation’s members. The method returns `null` if the annotation is not found, which will be the case if the annotation does not have `RUNTIME` retention.

Here is a program that assembles all of the pieces shown earlier and uses reflection to display the annotation associated with a method:

```java
import java.lang.annotation.*;
import java.lang.reflect.*;

// An annotation type declaration.
@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
    String str();
    int val();
}

class Meta {

    // Annotate a method.
    @MyAnno(str = "Annotation Example", val = 100)
    public static void myMeth() {
        Meta ob = new Meta();

        // Obtain the annotation for this method
        // and display the values of the members.
```
The output from the program is shown here:

```
try {
    // First, get a Class object that represents 
    // this class.
    Class<?> c = ob.getClass();

    // Now, get a Method object that represents 
    // this method.
    Method m = c.getMethod("myMeth");

    // Next, get the annotation for this class.
    MyAnno anno = m.getAnnotation(MyAnno.class);

    // Finally, display the values.
    System.out.println(anno.str() + " " + anno.val());
} catch (NoSuchMethodException exc) {
    System.out.println("Method Not Found.");
}
```

```
public static void main(String args[]) {
    myMeth();
}
```

The output from the program is shown here:

Annotation Example 100

This program uses reflection as described to obtain and display the values of `str` and `val` in the `MyAnno` annotation associated with `myMeth()` in the `Meta` class. There are two things to pay special attention to. First, in this line

```
MyAnno anno = m.getAnnotation(MyAnno.class);
```

notice the expression `MyAnno.class`. This expression evaluates to a `Class` object of type `MyAnno`, the annotation. This construct is called a `class literal`. You can use this type of expression whenever a `Class` object of a known class is needed. For example, this statement could have been used to obtain the `Class` object for `Meta`:

```
Class<?> c = Meta.class;
```

Of course, this approach only works when you know the class name of an object in advance, which might not always be the case. In general, you can obtain a class literal for classes, interfaces, primitive types, and arrays. (Remember, the `<?>` syntax
relates to Java’s generics feature. It is described in Chapter 14.)

The second point of interest is the way the values associated with `str` and `val` are obtained when they are output by the following line:

```java
System.out.println(anno.str() + " " + anno.val());
```

Notice that they are invoked using the method-call syntax. This same approach is used whenever the value of an annotation member is required.

**A Second Reflection Example**

In the preceding example, `myMeth()` has no parameters. Thus, when `getMethod()` was called, only the name `myMeth` was passed. However, to obtain a method that has parameters, you must specify class objects representing the types of those parameters as arguments to `getMethod()`. For example, here is a slightly different version of the preceding program:
import java.lang.annotation.*;
import java.lang.reflect.*;

@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
    String str();
    int val();
}

class Meta {

    // myMeth now has two arguments.
    @MyAnno(str = "Two Parameters", val = 19)
    public static void myMeth(String str, int i) {
        Meta ob = new Meta();

        try {
            Class<?> c = ob.getClass();

            // Here, the parameter types are specified.
            Method m = c.getMethod("myMeth", String.class, int.class)
            MyAnno anno = m.getAnnotation(MyAnno.class);
            System.out.println(anno.str() + " " + anno.val());
        } catch (NoSuchMethodException exc) {
            System.out.println("Method Not Found.");
        }  
    }

    public static void main(String args[]) {  
        myMeth("test", 10);
    }
}

The output from this version is shown here:

Two Parameters 19

In this version, myMeth() takes a String and an int parameter. To obtain information about this method, getMethod() must be called as shown here:
Method m = c.getMethod("myMeth", String.class, int.class);
Here, the Class objects representing String and int are passed as additional arguments.

**Obtaining All Annotations**

You can obtain all annotations that have RUNTIME retention that are associated with an item by calling getAnnotations() on that item. It has this general form:

```java
Annotation[] getAnnotations()
```

It returns an array of the annotations. getAnnotations() can be called on objects of type Class, Method, Constructor, and Field, among others.

Here is another reflection example that shows how to obtain all annotations associated with a class and with a method. It declares two annotations. It then uses those annotations to annotate a class and a method.

```java
// Show all annotations for a class and a method.
import java.lang.annotation. *;
import java.lang.reflect. *;

@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
   String str();
   int val();
}

@Retention(RetentionPolicy.RUNTIME)
@interface What {
   String description();
}

@What(description = "An annotation test class")
@MyAnno(str = "Meta2", val = 99)
class Meta2 {
```
The program uses `getAnnotations()` to obtain an array of all annotations associated with the `Meta2` class and with the `myMeth()` method. As explained,
getAnnotations() returns an array of Annotation objects. Recall that Annotation is a super-interface of all annotation interfaces and that it overrides toString() in Object. Thus, when a reference to an Annotation is output, its toString() method is called to generate a string that describes the annotation, as the preceding output shows.

The AnnotatedElement Interface

The methods getAnnotation() and getAnnotations() used by the preceding examples are defined by the AnnotatedElement interface, which is defined in java.lang.reflect. This interface supports reflection for annotations and is implemented by the classes Method, Field, Constructor, Class, and Package, among others.

In addition to getAnnotation() and getAnnotations(), AnnotatedElement defines several other methods. Two have been available since JDK 5. The first is getDeclaredAnnotations(), which has this general form:

Annotation[ ] getDeclaredAnnotations()

It returns all non-inherited annotations present in the invoking object. The second is isAnnotationPresent(), which has this general form:

default boolean isAnnotationPresent(Class<? extends Annotation> annoType)

It returns true if the annotation specified by annoType is associated with the invoking object. It returns false otherwise. To these, JDK 8 added getDeclaredAnnotation(), getAnnotationsByType(), and getDeclaredAnnotationsByType(). Of these, the last two automatically work with a repeated annotation.(Repeated annotations are discussed at the end of this chapter.)

Using Default Values

You can give annotation members default values that will be used if no value is specified when the annotation is applied. A default value is specified by adding a default clause to a member’s declaration. It has this general form:

    type member( ) default value ;

Here, value must be of a type compatible with type.

Here is @MyAnno rewritten to include default values:
This declaration gives a default value of "Testing" to `str` and 9000 to `val`. This means that neither value needs to be specified when `@MyAnno` is used. However, either or both can be given values if desired. Therefore, following are the four ways that `@MyAnno` can be used:

```java
@MyAnno() // both str and val default
@MyAnno(str = "some string") // val defaults
@MyAnno(val = 100) // str defaults
@MyAnno(str = "Testing", val = 100) // no defaults
```

The following program demonstrates the use of default values in an annotation.

```java
import java.lang.annotation.*;
import java.lang.reflect.*;

// An annotation type declaration that includes defaults.
@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
    String str() default "Testing";
    int val() default 9000;
}

class Meta3 {

    // Annotate a method using the default values.
    @MyAnno()
    public static void myMeth() {
        Meta3 ob = new Meta3();

        // Obtain the annotation for this method
        // and display the values of the members.
        try {
            Class<?> c = ob.getClass();
            Method m = c.getMethod("myMeth");
        }
    }
}
A marker annotation is a special kind of annotation that contains no members. Its sole purpose is to mark an item. Thus, its presence as an annotation is sufficient. The best way to determine if a marker annotation is present is to use the method `isAnnotationPresent()` , which is defined by the `AnnotatedElement` interface.

Here is an example that uses a marker annotation. Because a marker interface contains no members, simply determining whether it is present or absent is sufficient.
import java.lang.annotation.*;
import java.lang.reflect.*;

// A marker annotation.
@Retention(RetentionPolicy.RUNTIME)
@interface MyMarker {}

class Marker {

    // Annotate a method using a marker.
    // Notice that no ( ) is needed.
    @MyMarker
    public static void myMeth() {
        Marker ob = new Marker();

        try {
            Method m = ob.getClass().getMethod("myMeth");

            // Determine if the annotation is present.
            if(m.isAnnotationPresent(MyMarker.class))
                System.out.println("MyMarker is present.");
        }
        catch (NoSuchMethodException exc) {
            System.out.println("Method Not Found.");
        }
    }

    public static void main(String args[]) {
        myMeth();
    }
}

The output, shown here, confirms that @MyMarker is present:

    MyMarker is present.

In the program, notice that you do not need to follow @MyMarker with parentheses when it is applied. Thus, @MyMarker is applied simply by using its name, like this:

    @MyMarker

It is not wrong to supply an empty set of parentheses, but they are not needed.
Single-Member Annotations

A *single-member* annotation contains only one member. It works like a normal annotation except that it allows a shorthand form of specifying the value of the member. When only one member is present, you can simply specify the value for that member when the annotation is applied—you don’t need to specify the name of the member. However, in order to use this shorthand, the name of the member must be `value`.

Here is an example that creates and uses a single-member annotation:

```java
import java.lang.annotation.*;
import java.lang.reflect.*;

// A single-member annotation.
@Retention(RetentionPolicy.RUNTIME)
@interface MySingle {
    int value(); // this variable name must be value
}

class Single {

    // Annotate a method using a single-member annotation.
    @MySingle(100)
    public static void myMeth() {
        Single ob = new Single();

        try {
            Method m = ob.getClass().getMethod("myMeth");

            MySingle anno = m.getAnnotation(MySingle.class);

            System.out.println(anno.value()); // displays 100
        } catch (NoSuchMethodException exc) {
            System.out.println("Method Not Found.");
        }
    }

    public static void main(String args[]) {
        myMeth();
    }
}
```

As expected, this program displays the value 100. In the program, `@MySingle` is
used to annotate `mymeth()`, as shown here:

```java
@MySingle(100)
```

Notice that `value =` need not be specified.

You can use the single-value syntax when applying an annotation that has other members, but those other members must all have default values. For example, here the value `xyz` is added, with a default value of zero:

```java
@interface SomeAnno {
  int value();
  int xyz() default 0;
}
```

In cases in which you want to use the default for `xyz`, you can apply `@SomeAnno`, as shown next, by simply specifying the value of `value` by using the single-member syntax.

```java
@SomeAnno(88)
```

In this case, `xyz` defaults to zero, and `value` gets the value 88. Of course, to specify a different value for `xyz` requires that both members be explicitly named, as shown here:

```java
@SomeAnno(value = 88, xyz = 99)
```

Remember, whenever you are using a single-member annotation, the name of that member must be `value`.

### The Built-In Annotations

Java defines many built-in annotations. Most are specialized, but nine are general purpose. Of these, four are imported from `java.lang.annotation`: `@Retention`, `@Documented`, `@Target`, and `@Inherited`. Five—`@Override`, `@Deprecated`, `@FunctionalInterface`, `@SafeVarargs`, and `@SuppressWarnings`—are included in `java.lang`. Each is described here.

**NOTE** To `java.lang.annotation`, JDK 8 added the annotations `Repeatable` and `Native`. `Repeatable` supports repeatable annotations, as described later in this chapter. `Native` annotates a field that can be accessed by native code.

```java
@Retention
@Retention is designed to be used only as an annotation to another annotation. It specifies the retention policy as described earlier in this chapter.

@Documented
The @Documented annotation is a marker interface that tells a tool that an annotation is to be documented. It is designed to be used only as an annotation to an annotation declaration.

@Target
The @Target annotation specifies the types of items to which an annotation can be applied. It is designed to be used only as an annotation to another annotation. @Target takes one argument, which is an array of constants of the ElementType enumeration. This argument specifies the types of declarations to which the annotation can be applied. The constants are shown here along with the type of declaration to which they correspond:

<table>
<thead>
<tr>
<th>Target Constant</th>
<th>Annotation Can Be Applied To</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANNOTATION_TYPE</td>
<td>Another annotation</td>
</tr>
<tr>
<td>CONSTRUCTOR</td>
<td>Constructor</td>
</tr>
<tr>
<td>FIELD</td>
<td>Field</td>
</tr>
<tr>
<td>LOCAL_VARIABLE</td>
<td>Local variable</td>
</tr>
<tr>
<td>METHOD</td>
<td>Method</td>
</tr>
<tr>
<td>MODULE</td>
<td>Module (Added by JDK 9.)</td>
</tr>
<tr>
<td>PACKAGE</td>
<td>Package</td>
</tr>
<tr>
<td>PARAMETER</td>
<td>Parameter</td>
</tr>
<tr>
<td>TYPE</td>
<td>Class, interface, or enumeration</td>
</tr>
<tr>
<td>TYPE_PARAMETER</td>
<td>Type parameter</td>
</tr>
<tr>
<td>TYPE_USE</td>
<td>Type use</td>
</tr>
</tbody>
</table>

You can specify one or more of these values in a @Target annotation. To specify multiple values, you must specify them within a braces-delimited list. For example, to specify that an annotation applies only to fields and local variables, you can use this @Target annotation:

```java
@Target( { ElementType.FIELD, ElementType.LOCAL_VARIABLE } )
```
If you don't use `@Target`, then, except for type parameters, the annotation can be used on any declaration. For this reason, it is often a good idea to explicitly specify the target or targets so as to clearly indicate the intended uses of an annotation.

`@Inherited`

`@Inherited` is a marker annotation that can be used only on another annotation declaration. Furthermore, it affects only annotations that will be used on class declarations. `@Inherited` causes the annotation for a superclass to be inherited by a subclass. Therefore, when a request for a specific annotation is made to the subclass, if that annotation is not present in the subclass, then its superclass is checked. If that annotation is present in the superclass, and if it is annotated with `@Inherited`, then that annotation will be returned.

`@Override`

`@Override` is a marker annotation that can be used only on methods. A method annotated with `@Override` must override a method from a superclass. If it doesn’t, a compile-time error will result. It is used to ensure that a superclass method is actually overridden, and not simply overloaded.

`@Deprecated`

`@Deprecated` indicates that a declaration is obsolete and not recommended for use. Beginning with JDK 9, `@Deprecated` also allows you to specify the Java version in which the deprecation occurred and whether the deprecated element is slated for removal.

`@FunctionalInterface`

`@FunctionalInterface` is a marker annotation designed for use on interfaces. It indicates that the annotated interface is a functional interface. A functional interface is an interface that contains one and only one abstract method. Functional interfaces are used by lambda expressions. (See Chapter 15 for details on functional interfaces and lambda expressions.) If the annotated interface is not a functional interface, a compilation error will be reported. It is important to understand that `@FunctionalInterface` is not needed to create a functional interface. Any interface with exactly one abstract method is, by definition, a functional interface. Thus, `@FunctionalInterface` is purely informational.

`@SafeVarargs`
@SafeVarargs is a marker annotation that can be applied to methods and constructors. It indicates that no unsafe actions related to a varargs parameter occur. It is used to suppress unchecked warnings on otherwise safe code as it relates to non-reifiable vararg types and parameterized array instantiation. (A non-reifiable type is, essentially, a generic type. Generics are described in Chapter 14.) It must be applied only to vararg methods or constructors. Methods must also be static, final, or private.

@SuppressWarnings
@SuppressWarnings specifies that one or more warnings that might be issued by the compiler are to be suppressed. The warnings to suppress are specified by name, in string form.

Type Annotations

Beginning with JDK 8, the places in which annotations can be used has been expanded. As mentioned earlier, annotations were originally allowed only on declarations. However, now, annotations can also be specified in most cases in which a type is used. This expanded aspect of annotations is called type annotation. For example, you can annotate the return type of a method, the type of this within a method, a cast, array levels, an inherited class, and a throws clause. You can also annotate generic types, including generic type parameter bounds and generic type arguments. (See Chapter 14 for a discussion of generics.)

Type annotations are important because they enable tools to perform additional checks on code to help prevent errors. Understand that, as a general rule, javac will not perform these checks, itself. A separate tool is used for this purpose, although such a tool might operate as a compiler plug-in.

A type annotation must include ElementType.TYPE_USE as a target. (Recall that valid annotation targets are specified using the @Target annotation, as previously described.) A type annotation applies to the type that the annotation precedes. For example, assuming some type annotation called @TypeAnno, the following is legal:

```java
void myMeth() throws @TypeAnno NullPointerException { // ... }
```

Here, @TypeAnno annotates NullPointerException in the throws clause.

You can also annotate the type of this (called the receiver). As you know, this is an implicit argument to all instance methods and it refers to the invoking object. To annotate its type requires the use of another new JDK 8 feature. Beginning with JDK
8, you can explicitly declare `this` as the first parameter to a method. In this declaration, the type of `this` must be the type of its class; for example:

class SomeClass {
    int myMeth(SomeClass this, int i, int j) { // ...  
}

Here, because `myMeth()` is a method defined by `SomeClass`, the type of `this` is `SomeClass`. Using this declaration, you can now annotate the type of `this`. For example, again assuming that `@TypeAnno` is a type annotation, the following is legal:

```plaintext
int myMeth(@TypeAnno SomeClass this, int i, int j) { // ...  
```

It is important to understand that it is not necessary to declare `this` unless you are annotating it. (If `this` is not declared, it is still implicitly passed, as it always has been.) Also, explicitly declaring `this` does not change any aspect of the method’s signature because `this` is implicitly declared, by default. Again, you will declare `this` only if you want to apply a type annotation to it. If you do declare `this`, it must be the first parameter.

The following program shows a number of the places that a type annotation can be used. It defines several annotations, of which several are for type annotation. The names and targets of the annotations are shown here:

<table>
<thead>
<tr>
<th>Annotation</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>@TypeAnno</td>
<td>ElementType.TYPE_USE</td>
</tr>
<tr>
<td>@MaxLen</td>
<td>ElementType.TYPE_USE</td>
</tr>
<tr>
<td>@NotZeroLen</td>
<td>ElementType.TYPE_USE</td>
</tr>
<tr>
<td>@Unique</td>
<td>ElementType.TYPE_USE</td>
</tr>
<tr>
<td>@What</td>
<td>ElementType.TYPE_PARAMETER</td>
</tr>
<tr>
<td>@EmptyOK</td>
<td>ElementType.FIELD</td>
</tr>
<tr>
<td>@Recommended</td>
<td>ElementType.METHOD</td>
</tr>
</tbody>
</table>

Notice that `@EmptyOK`, `@Recommended`, and `@What` are not type annotations. They are included for comparison purposes. Of special interest is `@What`, which is used to annotate a generic type parameter declaration. The comments in the program describe each use.
// Demonstrate several type annotations.
import java.lang.annotation.*;
import java.lang.reflect.*;

// A marker annotation that can be applied to a type.
@Target(ElementType.TYPE_USE)
@interface TypeAnno { }

// Another marker annotation that can be applied to a type.
@Target(ElementType.TYPE_USE)
@interface NotZeroLen { }

// Still another marker annotation that can be applied to a type.
@Target(ElementType.TYPE_USE)
@interface Unique { }

// A parameterized annotation that can be applied to a type.
@Target(ElementType.TYPE_USE)
@interface MaxLen {
    int value();
}
// An annotation that can be applied to a type parameter.
@Target(ElementType.TYPE_PARAMETER)
@interface What {
    String description();
}

// An annotation that can be applied to a field declaration.
@Target(ElementType.FIELD)
@interface EmptyOK {
}

// An annotation that can be applied to a method declaration.
@Target(ElementType.METHOD)
@interface Recommended {
}

// Use an annotation on a type parameter.
class TypeAnnoDemo<@What(description = "Generic data type") T> {

    // Use a type annotation on a constructor.
    public @Unique TypeAnnoDemo() {
    }

    // Annotate the type (in this case String), not the field.
    @TypeAnno String str;
// This annotates the field test.
@EmptyOK String test;

// Use a type annotation to annotate this (the receiver).
public int f(@TypeAnno TypeAnnoDemo<T> this, int x) {
    return 10;
}

// Annotate the return type.
public @TypeAnno Integer f2(int j, int k) {
    return j+k;
}

// Annotate the method declaration.
public @Recommended Integer f3(String str) {
    return str.length() / 2;
}

// Use a type annotation with a throws clause.
public void f4() throws @TypeAnno NullPointerException {
    // ...
}

// Annotate array levels.
String @MaxLen(10) [] @NotZeroLen [] w;

// Annotate the array element type.
@TypeAnno Integer[] vec;
Although what most of the annotations in the preceding program refer to is clear, four uses require a bit of discussion. The first is the annotation of a method return type versus the annotation of a method declaration. In the program, pay special attention to these two method declarations:

```java
public static void myMeth(int i) {
    // Use a type annotation on a type argument.
    TypeAnnoDemo<@TypeAnno Integer> ob =
            new TypeAnnoDemo<@TypeAnno Integer>();

    // Use a type annotation with new.
    @Unique TypeAnnoDemo<Integer> ob2 = new @Unique TypeAnnoDemo<Integer>();

    Object x = Integer.valueOf(10);
    Integer y;

    // Use a type annotation on a cast.
    y = (@TypeAnno Integer) x;
}
```

Notice that in both cases, an annotation precedes the method’s return type (which is `Integer`). However, the two annotations annotate two different things. In the first case, the `@TypeAnno` annotation annotates `f2()`’s return type. This is because `@TypeAnno` has its target specified as `ElementType.TYPE_USE`, which means
that it can be used to annotate type uses. In the second case, \texttt{@Recommended} annotates the method declaration, itself. This is because \texttt{@Recommended} has its target specified as \texttt{ElementType.METHOD}. As a result, \texttt{@Recommended} applies to the declaration, not the return type. Therefore, the target specification is used to eliminate what, at first glance, appears to be ambiguity between the annotation of a method declaration and the annotation of the method’s return type.

One other thing about annotating a method return type: You cannot annotate a return type of \texttt{void}.

The second point of interest are the field annotations, shown here:

```java
// Annotate the type (in this case String), not the field.
@TypeAnno String str;

// This annotates the field test.
@EmptyOK String test;
```

Here, \texttt{@TypeAnno} annotates the type \texttt{String}, but \texttt{@EmptyOK} annotates the field \texttt{test}. Even though both annotations precede the entire declaration, their targets are different, based on the target element type. If the annotation has the \texttt{ElementType.TYPE_USE} target, then the type is annotated. If it has \texttt{ElementType.FIELD} as a target, then the field is annotated. Thus, the situation is similar to that just described for methods, and no ambiguity exists. The same mechanism also disambiguates annotations on local variables.

Next, notice how \texttt{this} (the receiver) is annotated here:

```java
public int f(@TypeAnno TypeAnnoDemo<T> this, int x) {
```

Here, \texttt{this} is specified as the first parameter and is of type \texttt{TypeAnnoDemo} (which is the class of which \texttt{f()} is a member). As explained, beginning with JDK 8, an instance method declaration can explicitly specify the \texttt{this} parameter for the sake of applying a type annotation.

Finally, look at how array levels are annotated by the following statement:

```java
String @MaxLen(10) [] @NotZeroLen [] w;
```

In this declaration, \texttt{@MaxLen} annotates the type of the first level and \texttt{@NotZeroLen} annotates the type of the second level. In this declaration

```java
@TypeAnno Integer[] vec;
```

the element type \texttt{Integer} is annotated.
Repeating Annotations

Beginning with JDK 8, an annotation can be repeated on the same element. This is called repeating annotations. For an annotation to be repeatable, it must be annotated with the @Repeatable annotation, defined in java.lang.annotation. Its value field specifies the container type for the repeatable annotation. The container is specified as an annotation for which the value field is an array of the repeatable annotation type. Thus, to create a repeatable annotation, you must create a container annotation and then specify that annotation type as an argument to the @Repeatable annotation.

To access the repeated annotations using a method such as getAnnotation(), you will use the container annotation, not the repeatable annotation. The following program shows this approach. It converts the version of MyAnno shown previously into a repeatable annotation and demonstrates its use.

```java
// Demonstrate a repeated annotation.
import java.lang.annotation.*;
import java.lang.reflect.*;

// Make MyAnno repeatable.
@Retention(RetentionPolicy.RUNTIME)
@Repeatable(MyRepeatedAnnos.class)
@interface MyAnno {
    String str() default "Testing";
    int val() default 9000;
}

// This is the container annotation.
@Retention(RetentionPolicy.RUNTIME)
@interface MyRepeatedAnnos {
    MyAnno[] value();
}

class RepeatAnno {
    // Repeat MyAnno on myMeth().
    @MyAnno(str = "First annotation", val = -1)
    @MyAnno(str = "Second annotation", val = 100)
    public static void myMeth(String str, int i)
As explained, in order for MyAnno to be repeatable, it must be annotated with the @Repeatable annotation, which specifies its container annotation. The container annotation is called MyRepeatedAnnos. The program accesses the repeated annotations by calling getAnnotation( ), passing in the class of the container annotation, not the repeatable annotation, itself. As the output shows, the repeated annotations are separated by a comma. They are not returned individually.

Another way to obtain the repeated annotations is to use one of the methods in AnnotatedElement that can operate directly on a repeated annotation. These are getAnnotationsByType( ) and getDeclaredAnnotationsByType( ). Here, we will use the former. It is shown here:

default <T extends Annotation> T[ ] getAnnotationsByType(Class<T> annoType)

It returns an array of the annotations of annoType associated with the invoking object. If no annotations are present, the array will be of zero length. Here is an
example. Assuming the preceding program, the following sequence uses `getAnnotationsByType()` to obtain the repeated `MyAnno` annotations:

```java
Annotation[] annos = m.getAnnotationsByType(MyAnno.class);
for(Annotation a : annos)
    System.out.println(a);
```

Here, the repeated annotation type, which is `MyAnno`, is passed to `getAnnotationsByType()`. The returned array contains all of the instances of `MyAnno` associated with `myMeth()`, which, in this example, is two. Each repeated annotation can be accessed via its index in the array. In this case, each `MyAnno` annotation is displayed via a for-each loop.

### Some Restrictions

There are a number of restrictions that apply to annotation declarations. First, no annotation can inherit another. Second, all methods declared by an annotation must be without parameters. Furthermore, they must return one of the following:

- A primitive type, such as `int` or `double`
- An object of type `String` or `Class`
- An object of an `enum` type
- An object of another annotation type
- An array of a legal type.

Annotations cannot be generic. In other words, they cannot take type parameters. (Generics are described in Chapter 14.) Finally, annotation methods cannot specify a `throws` clause.
This chapter introduces one of Java’s most important packages, java.io, which supports Java’s basic I/O (input/output) system, including file I/O. Support for I/O comes from Java’s core API libraries, not from language keywords. For this reason, an in-depth discussion of this topic is found in Part II of this book, which examines several of Java’s API packages. Here, the foundation of this important subsystem is introduced so that you can see how it fits into the larger context of the Java programming and execution environment. This chapter also examines the try-with-resources statement and several more Java keywords: transient, volatile, instanceof, native, strictfp, and assert. It concludes by discussing static import and describing another use for the this keyword.

I/O Basics

As you may have noticed while reading the preceding 12 chapters, not much use has been made of I/O in the example programs. In fact, aside from print( ) and println( ), none of the I/O methods have been used significantly. The reason is simple: most real applications of Java are not text-based, console programs. Rather, they are either graphically oriented programs that rely on one of Java’s graphical user interface (GUI) frameworks, such as Swing, the AWT, or JavaFX, for user interaction, or they are Web applications. Although text-based, console programs are excellent as teaching examples, they do not constitute an important use for Java in the real world. Also, Java’s support for console I/O is limited and somewhat awkward to use—even in simple example programs. Text-based console I/O is just not that useful in real-world Java programming.

The preceding paragraph notwithstanding, Java does provide strong, flexible support for I/O as it relates to files and networks. Java’s I/O system is cohesive and consistent. In fact, once you understand its fundamentals, the rest of the I/O system is easy to master. A general overview of I/O is presented here. A detailed description is found in Chapters 21 and 22.

Streams
Java programs perform I/O through streams. A *stream* is an abstraction that either produces or consumes information. A stream is linked to a physical device by the Java I/O system. All streams behave in the same manner, even if the actual physical devices to which they are linked differ. Thus, the same I/O classes and methods can be applied to different types of devices. This means that an input stream can abstract many different kinds of input: from a disk file, a keyboard, or a network socket. Likewise, an output stream may refer to the console, a disk file, or a network connection. Streams are a clean way to deal with input/output without having every part of your code understand the difference between a keyboard and a network, for example. Java implements streams within class hierarchies defined in the `java.io` package.

**NOTE** In addition to the stream-based I/O defined in `java.io`, Java also provides buffer- and channel-based I/O, which is defined in `java.nio` and its subpackages. They are described in Chapter 22.

### Byte Streams and Character Streams
Java defines two types of streams: byte and character. *Byte streams* provide a convenient means for handling input and output of bytes. Byte streams are used, for example, when reading or writing binary data. *Character streams* provide a convenient means for handling input and output of characters. They use Unicode and, therefore, can be internationalized. Also, in some cases, character streams are more efficient than byte streams.

The original version of Java (Java 1.0) did not include character streams and, thus, all I/O was byte-oriented. Character streams were added by Java 1.1, and certain byte-oriented classes and methods were deprecated. Although old code that doesn’t use character streams is becoming increasingly rare, it may still be encountered from time to time. As a general rule, old code should be updated to take advantage of character streams where appropriate.

One other point: at the lowest level, all I/O is still byte-oriented. The character-based streams simply provide a convenient and efficient means for handling characters.

An overview of both byte-oriented streams and character-oriented streams is presented in the following sections.

### The Byte Stream Classes
Byte streams are defined by using two class hierarchies. At the top are two abstract classes: `InputStream` and `OutputStream`. Each of these abstract classes has several
concrete subclasses that handle the differences among various devices, such as disk files, network connections, and even memory buffers. The byte stream classes in java.io are shown in Table 13-1. A few of these classes are discussed later in this section. Others are described in Part II of this book. Remember, to use the stream classes, you must import java.io.

<table>
<thead>
<tr>
<th>Stream Class</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>BufferedInputStream</td>
<td>Buffered input stream</td>
</tr>
<tr>
<td>BufferedOutputStream</td>
<td>Buffered output stream</td>
</tr>
<tr>
<td>ByteArrayInputStream</td>
<td>Input stream that reads from a byte array</td>
</tr>
<tr>
<td>ByteArrayOutputStream</td>
<td>Output stream that writes to a byte array</td>
</tr>
<tr>
<td>DataInputStream</td>
<td>An input stream that contains methods for reading the Java standard data types</td>
</tr>
<tr>
<td>DataOutputStream</td>
<td>An output stream that contains methods for writing the Java standard data types</td>
</tr>
<tr>
<td>FileInputStream</td>
<td>Input stream that reads from a file</td>
</tr>
<tr>
<td>FileOutputStream</td>
<td>Output stream that writes to a file</td>
</tr>
<tr>
<td>FilterInputStream</td>
<td>Implements InputStream</td>
</tr>
<tr>
<td>FilterOutputStream</td>
<td>Implements OutputStream</td>
</tr>
<tr>
<td>InputStream</td>
<td>Abstract class that describes stream input</td>
</tr>
<tr>
<td>ObjectInputStream</td>
<td>Input stream for objects</td>
</tr>
<tr>
<td>ObjectOutputStream</td>
<td>Output stream for objects</td>
</tr>
<tr>
<td>OutputStream</td>
<td>Abstract class that describes stream output</td>
</tr>
<tr>
<td>PipedInputStream</td>
<td>Input pipe</td>
</tr>
<tr>
<td>PipedOutputStream</td>
<td>Output pipe</td>
</tr>
<tr>
<td>PrintStream</td>
<td>Output stream that contains print() and println()</td>
</tr>
<tr>
<td>PushbackInputStream</td>
<td>Input stream that allows bytes to be returned to the input stream.</td>
</tr>
<tr>
<td>SequenceInputStream</td>
<td>Input stream that is a combination of two or more input streams that will be read sequentially, one after the other</td>
</tr>
</tbody>
</table>

Table 13-1  The Byte Stream Classes in java.io

The abstract classes InputStream and OutputStream define several key methods that the other stream classes implement. Two of the most important are
read() and write(), which, respectively, read and write bytes of data. Each has a form that is abstract and must be overridden by derived stream classes.

The Character Stream Classes
Character streams are defined by using two class hierarchies. At the top are two abstract classes: Reader and Writer. These abstract classes handle Unicode character streams. Java has several concrete subclasses of each of these. The character stream classes in java.io are shown in Table 13-2.

<table>
<thead>
<tr>
<th>Stream Class</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>BufferedReader</td>
<td>Buffered input character stream</td>
</tr>
<tr>
<td>BufferedWriter</td>
<td>Buffered output character stream</td>
</tr>
<tr>
<td>CharArrayReader</td>
<td>Input stream that reads from a character array</td>
</tr>
<tr>
<td>CharArrayWriter</td>
<td>Output stream that writes to a character array</td>
</tr>
<tr>
<td>FileReader</td>
<td>Input stream that reads from a file</td>
</tr>
<tr>
<td>FileWriter</td>
<td>Output stream that writes to a file</td>
</tr>
<tr>
<td>FilterReader</td>
<td>Filtered reader</td>
</tr>
<tr>
<td>FilterWriter</td>
<td>Filtered writer</td>
</tr>
<tr>
<td>InputStreamReader</td>
<td>Input stream that translates bytes to characters</td>
</tr>
<tr>
<td>LineNumberReader</td>
<td>Input stream that counts lines</td>
</tr>
<tr>
<td>OutputStreamWriter</td>
<td>Output stream that translates characters to bytes</td>
</tr>
<tr>
<td>PipedReader</td>
<td>Input pipe</td>
</tr>
<tr>
<td>PipedWriter</td>
<td>Output pipe</td>
</tr>
<tr>
<td>PrintWriter</td>
<td>Output stream that contains print() and println()</td>
</tr>
<tr>
<td>PushbackReader</td>
<td>Input stream that allows characters to be returned to the input stream</td>
</tr>
<tr>
<td>Reader</td>
<td>Abstract class that describes character stream input</td>
</tr>
<tr>
<td>StringReader</td>
<td>Input stream that reads from a string</td>
</tr>
<tr>
<td>StringWriter</td>
<td>Output stream that writes to a string</td>
</tr>
<tr>
<td>Writer</td>
<td>Abstract class that describes character stream output</td>
</tr>
</tbody>
</table>

Table 13-2 The Character Stream I/O Classes in java.io

The abstract classes Reader and Writer define several key methods that the other
stream classes implement. Two of the most important methods are `read()` and `write()`, which read and write characters of data, respectively. Each has a form that is abstract and must be overridden by derived stream classes.

**The Predefined Streams**

As you know, all Java programs automatically import the `java.lang` package. This package defines a class called `System`, which encapsulates several aspects of the run-time environment. For example, using some of its methods, you can obtain the current time and the settings of various properties associated with the system. `System` also contains three predefined stream variables: `in`, `out`, and `err`. These fields are declared as `public`, `static`, and `final` within `System`. This means that they can be used by any other part of your program and without reference to a specific `System` object.

`System.out` refers to the standard output stream. By default, this is the console. `System.in` refers to standard input, which is the keyboard by default. `System.err` refers to the standard error stream, which also is the console by default. However, these streams may be redirected to any compatible I/O device.

`System.in` is an object of type `InputStream`; `System.out` and `System.err` are objects of type `PrintStream`. These are byte streams, even though they are typically used to read and write characters from and to the console. As you will see, you can wrap these within character-based streams, if desired.

The preceding chapters have been using `System.out` in their examples. You can use `System.err` in much the same way. As explained in the next section, use of `System.in` is a little more complicated.

**Reading Console Input**

In the early days of Java, the only way to perform console input was to use a byte stream. Today, using a byte stream to read console input is still acceptable. However, for commercial applications, the preferred method of reading console input is to use a character-oriented stream. This makes your program easier to internationalize and maintain.

In Java, console input is accomplished by reading from `System.in`. To obtain a character-based stream that is attached to the console, wrap `System.in` in a `BufferedReader` object. `BufferedReader` supports a buffered input stream. A commonly used constructor is shown here:

```java
BufferedReader(Reader inputReader)
```
Here, inputReader is the stream that is linked to the instance of BufferedReader that is being created. Reader is an abstract class. One of its concrete subclasses is InputStreamReader, which converts bytes to characters. To obtain an InputStreamReader object that is linked to System.in, use the following constructor:

```
InputStreamReader(InputStream inputStream)
```

Because System.in refers to an object of type InputStream, it can be used for inputStream. Putting it all together, the following line of code creates a BufferedReader that is connected to the keyboard:

```
BufferedReader br = new BufferedReader(new InputStreamReader(System.in));
```

After this statement executes, br is a character-based stream that is linked to the console through System.in.

**Reading Characters**

To read a character from a BufferedReader, use read(). The version of read() that we will be using is

```
int read() throws IOException
```

Each time that read() is called, it reads a character from the input stream and returns it as an integer value. It returns -1 when an attempt is made to read at the end of the stream. As you can see, it can throw an IOException.

The following program demonstrates read() by reading characters from the console until the user types a "q." Notice that any I/O exceptions that might be generated are simply thrown out of main(). Such an approach is common when reading from the console in simple example programs such as those shown in this book, but in more sophisticated applications, you can handle the exceptions explicitly.
// Use a BufferedReader to read characters from the console.
import java.io.*;

class BRRead {
    public static void main(String args[]) throws IOException {
        char c;
        BufferedReader br = new
                       BufferedReader(new InputStreamReader(System.in));
        System.out.println("Enter characters, 'q' to quit.");
        // read characters
        do {
            c = (char) br.read();
            System.out.println(c);
        } while(c != 'q');
    }
}

Here is a sample run:

    Enter characters, 'q' to quit.
    123abcq
    1
    2
    3
    a
    b
    c
    q

This output may look a little different from what you expected because System.in is line buffered, by default. This means that no input is actually passed to the program until you press ENTER. As you can guess, this does not make read( ) particularly valuable for interactive console input.

Reading Strings

To read a string from the keyboard, use the version of readLine( ) that is a member of the BufferedReader class. Its general form is shown here:

    String readLine( ) throws IOException

As you can see, it returns a String object.

The following program demonstrates BufferedReader and the readLine( )
method; the program reads and displays lines of text until you enter the word "stop":

```java
// Read a string from console using a BufferedReader.
import java.io.*;

class BRReadLines {
    public static void main(String args[]) throws IOException {
        // create a BufferedReader using System.in
        BufferedReader br = new BufferedReader(new InputStreamReader(System.in));
        String str;
        System.out.println("Enter lines of text.");
        System.out.println("Enter 'stop' to quit.");
        do {
            str = br.readLine();
            System.out.println(str);
        } while(!str.equals("stop"));
    }
}
```

The next example creates a tiny text editor. It creates an array of *String* objects and then reads in lines of text, storing each line in the array. It will read up to 100 lines or until you enter "stop." It uses a *BufferedReader* to read from the console.
Here is a sample run:

Enter lines of text.
Enter 'stop' to quit.
This is line one.
This is line two.
Java makes working with strings easy.
Just create String objects.
stop

Here is your file:
This is line one.
This is line two.
Java makes working with strings easy.
Just create String objects.

Writing Console Output

Console output is most easily accomplished with print( ) and println( ), described
earlier, which are used in most of the examples in this book. These methods are
defined by the class PrintStream (which is the type of object referenced by
System.out). Even though System.out is a byte stream, using it for simple program
output is still acceptable. However, a character-based alternative is described in the
next section.

Because PrintStream is an output stream derived from OutputStream, it also
implements the low-level method write(). Thus, write() can be used to write to the
console. The simplest form of write() defined by PrintStream is shown here:

    void write(int byteval)

This method writes the byte specified by byteval. Although byteval is declared as an
integer, only the low-order eight bits are written. Here is a short example that uses
write() to output the character "A" followed by a newline to the screen:

    // Demonstrate System.out.write().
    class WriteDemo {
        public static void main(String args[]) {
            int b;

            b = 'A';
            System.out.write(b);
            System.out.write('
');
        }
    }

    You will not often use write() to perform console output (although doing so
might be useful in some situations) because print() and println() are substantially
easier to use.

The PrintWriter Class

Although using System.out to write to the console is acceptable, its use is probably
best for debugging purposes or for sample programs, such as those found in this
book. For real-world programs, the recommended method of writing to the console
when using Java is through a PrintWriter stream. PrintWriter is one of the
character-based classes. Using a character-based class for console output makes
internationalizing your program easier.

PrintWriter defines several constructors. The one we will use is shown here:

    PrintWriter(OutputStream outputStream, boolean flushingOn)
Here, outputStream is an object of type OutputStream, and flushingOn controls whether Java flushes the output stream every time a println() method (among others) is called. If flushingOn is true, flushing automatically takes place. If false, flushing is not automatic.

PrintWriter supports the print() and println() methods. Thus, you can use these methods in the same way as you used them with System.out. If an argument is not a simple type, the PrintWriter methods call the object’s toString() method and then display the result.

To write to the console by using a PrintWriter, specify System.out for the output stream and automatic flushing. For example, this line of code creates a PrintWriter that is connected to console output:

```java
PrintWriter pw = new PrintWriter(System.out, true);
```

The following application illustrates using a PrintWriter to handle console output:

```java
// Demonstrate PrintWriter
import java.io.*;

class PrintWriterDemo { 
    public static void main(String args[]) {
        PrintWriter pw = new PrintWriter(System.out, true);

        pw.println("This is a string");
        int i = -7;
        pw.println(i);
        double d = 4.5e-7;
        pw.println(d);
    }
}
```

The output from this program is shown here:

```
This is a string
-7
4.5E-7
```

Remember, there is nothing wrong with using System.out to write simple text output to the console when you are learning Java or debugging your programs. However, using a PrintWriter makes your real-world applications easier to internationalize. Because no advantage is gained by using a PrintWriter in the sample programs shown in this book, we will continue to use System.out to write to
the console.

## Reading and Writing Files

Java provides a number of classes and methods that allow you to read and write files. Before we begin, it is important to state that the topic of file I/O is quite large and file I/O is examined in detail in [Part II](#). The purpose of this section is to introduce the basic techniques that read from and write to a file. Although byte streams are used, these techniques can be adapted to the character-based streams.

Two of the most often-used stream classes are `FileInputStream` and `FileOutputStream`, which create byte streams linked to files. To open a file, you simply create an object of one of these classes, specifying the name of the file as an argument to the constructor. Although both classes support additional constructors, the following are the forms that we will be using:

```java
FileInputStream(String fileName) throws FileNotFoundException
FileOutputStream(String fileName) throws FileNotFoundException
```

Here, `fileName` specifies the name of the file that you want to open. When you create an input stream, if the file does not exist, then `FileNotFoundException` is thrown. For output streams, if the file cannot be opened or created, then `FileNotFoundException` is thrown. `FileNotFoundException` is a subclass of `IOException`. When an output file is opened, any preexisting file by the same name is destroyed.

**NOTE** In situations in which a security manager is present, several of the file classes, including `FileInputStream` and `FileOutputStream`, will throw a `SecurityException` if a security violation occurs when attempting to open a file. By default, applications run via `java` do not use a security manager. For that reason, the I/O examples in this book do not need to watch for a possible `SecurityException`. However, other types of applications may use the security manager, and file I/O performed by such an application could generate a `SecurityException`. In that case, you will need to appropriately handle this exception.

When you are done with a file, you must close it. This is done by calling the `close()` method, which is implemented by both `FileInputStream` and `FileOutputStream`. It is shown here:

```java
void close() throws IOException
```
Closing a file releases the system resources allocated to the file, allowing them to be used by another file. Failure to close a file can result in “memory leaks” because of unused resources remaining allocated.

**NOTE** Beginning with JDK 7, the `close()` method is specified by the `AutoCloseable` interface in `java.lang`. `AutoCloseable` is inherited by the `Closeable` interface in `java.io`. Both interfaces are implemented by the stream classes, including `FileInputStream` and `FileOutputStream`.

Before moving on, it is important to point out that there are two basic approaches that you can use to close a file when you are done with it. The first is the traditional approach, in which `close()` is called explicitly when the file is no longer needed. This is the approach used by all versions of Java prior to JDK 7 and is, therefore, found in all pre-JDK 7 legacy code. The second is to use the `try`-with-resources statement added by JDK 7, which automatically closes a file when it is no longer needed. In this approach, no explicit call to `close()` is executed. Since you may encounter pre-JDK 7 legacy code that is still being used and maintained, it is important that you know and understand the traditional approach. Therefore, we will begin with it. The automated approach is described in the following section.

To read from a file, you can use a version of `read()` that is defined within `FileInputStream`. The one that we will use is shown here:

```java
int read() throws IOException
```

Each time that it is called, it reads a single byte from the file and returns the byte as an integer value. `read()` returns –1 when an attempt is made to read at the end of the stream. It can throw an `IOException`.

The following program uses `read()` to input and display the contents of a file that contains ASCII text. The name of the file is specified as a command-line argument.
/* Display a text file.
   To use this program, specify the name
   of the file that you want to see.
   For example, to see a file called TEST.TXT,
   use the following command line.

   java ShowFile TEST.TXT

*/

import java.io.*;

class ShowFile {
    public static void main(String args[])
    {
        int i;
        FileInputStream fin;

        // First, confirm that a filename has been specified.
        if(args.length != 1) {
            System.out.println("Usage: ShowFile filename");
            return;
        }
    }
}
In the program, notice the `try/catch` blocks that handle the I/O errors that might occur. Each I/O operation is monitored for exceptions, and if an exception occurs, it is handled. Be aware that in simple programs or example code, it is common to see I/O exceptions simply thrown out of `main()`, as was done in the earlier console I/O examples. Also, in some real-world code, it can be helpful to let an exception propagate to a calling routine to let the caller know that an I/O operation failed. However, most of the file I/O examples in this book handle all I/O exceptions explicitly, as shown, for the sake of illustration.

Although the preceding example closes the file stream after the file is read, there is a variation that is often useful. The variation is to call `close()` within a `finally` block. In this approach, all of the methods that access the file are contained within a `try` block, and the `finally` block is used to close the file. This way, no matter how the `try` block terminates, the file is closed. Assuming the preceding example, here is how the `try` block that reads the file can be recoded:
try {
    do {
        i = fin.read();
        if (i != -1) System.out.print((char) i);
    } while (i != -1);
} catch (IOException e) {
    System.out.println("Error Reading File");

} finally {
    // Close file on the way out of the try block.
    try {
        fin.close();
    } catch (IOException e) {
        System.out.println("Error Closing File");
    }

}  /*
 Display a text file.
 To use this program, specify the name
 of the file that you want to see.
 For example, to see a file called TEST.TXT,
 use the following command line.

 java ShowFile TEST.TXT

 This variation wraps the code that opens and
 accesses the file within a single try block.
 The file is closed by the finally block.
 */
import java.io.*;

class ShowFile {
    public static void main(String args[]) {
        int i;
        FileInputStream fin = null;

        // First, confirm that a filename has been specified.
        if (args.length != 1) {
            System.out.println("Usage: ShowFile filename");
            return;
        }

        // The following code opens a file, reads characters until EOF
        // is encountered, and then closes the file via a finally block.
        try {
            fin = new FileInputStream(args[0]);

            do {
                i = fin.read();
                if (i != -1) System.out.println((char) i);
            } while (i != -1);

        } catch (FileNotFoundException e) {
            System.out.println("File Not Found.");
        } catch (IOException e) {
            System.out.println("An I/O Error Occurred");
        }
        finally {
            // Close file in all cases.
            try {
                if (fin != null) fin.close();
            } catch (IOException e) {
                System.out.println("Error Closing File");
            }
        }
    }
}

In this approach, notice that fin is initialized to null. Then, in the finally block, the file is closed only if fin is not null. This works because fin will be non-null only if the file is successfully opened. Thus, close() is not called if an exception occurs while opening the file.

It is possible to make the try/catch sequence in the preceding example a bit more
compact. Because `FileNotFoundException` is a subclass of `IOException`, it need not be caught separately. For example, here is the sequence recoded to eliminate catching `FileNotFoundException`. In this case, the standard exception message, which describes the error, is displayed.

```java
try {
    fin = new FileInputStream(args[0]);

    do {
        i = fin.read();
        if(i != -1) System.out.print((char) i);
    } while(i != -1);

} catch(IOException e) {
    System.out.println("I/O Error: " + e);
} finally {
    // Close file in all cases.
    try {
        if(fin != null) fin.close();
    } catch(IOException e) {
        System.out.println("Error Closing File");
    }
}
```

In this approach, any error, including an error opening the file, is simply handled by the single `catch` statement. Because of its compactness, this approach is used by many of the I/O examples in this book. Be aware, however, that this approach is not appropriate in cases in which you want to deal separately with a failure to open a file, such as might be caused if a user mistypes a filename. In such a situation, you might want to prompt for the correct name, for example, before entering a `try` block that accesses the file.

To write to a file, you can use the `write()` method defined by `FileOutputStream`. Its simplest form is shown here:

```java
void write(int byteval) throws IOException
```

This method writes the byte specified by `byteval` to the file. Although `byteval` is declared as an integer, only the low-order eight bits are written to the file. If an error occurs during writing, an `IOException` is thrown. The next example uses `write()` to copy a file:
/* Copy a file.
   To use this program, specify the name
   of the source file and the destination file.
   For example, to copy a file called FIRST.TXT
to a file called SECOND.TXT, use the following
command line.

    java CopyFile FIRST.TXT SECOND.TXT
*/

import java.io.*;

class CopyFile {
    public static void main(String args[]) throws IOException {
        int i;
        FileInputStream fin = null;
        FileOutputStream fout = null;

        // First, confirm that both files have been specified.
        if(args.length != 2) {
            System.out.println("Usage: CopyFile from to");
            return;
        }

        String fromFile = args[0];
        String toFile = args[1];

        // Open the input and output streams
        fin = new FileInputStream(fromFile);
        fout = new FileOutputStream(toFile);

        // Read and write the file
        while((i = fin.read()) != -1) {
            fout.write(i);
        }

        // Close the streams
        fin.close();
        fout.close();
    }
}
In the program, notice that two separate `try` blocks are used when closing the files. This ensures that both files are closed, even if the call to `fin.close()` throws an exception.

In general, notice that all potential I/O errors are handled in the preceding two programs by the use of exceptions. This differs from some computer languages that use error codes to report file errors. Not only do exceptions make file handling cleaner, but they also enable Java to easily differentiate the end-of-file condition from file errors when input is being performed.

**Automatically Closing a File**

In the preceding section, the example programs have made explicit calls to `close()` to
close a file once it is no longer needed. As mentioned, this is the way files were closed when using versions of Java prior to JDK 7. Although this approach is still valid and useful, JDK 7 added a feature that offers another way to manage resources, such as file streams, by automating the closing process. This feature, sometimes referred to as automatic resource management, or ARM for short, is based on an expanded version of the try statement. The principal advantage of automatic resource management is that it prevents situations in which a file (or other resource) is inadvertently not released after it is no longer needed. As explained, forgetting to close a file can result in memory leaks, and could lead to other problems.

Automatic resource management is based on an expanded form of the try statement. Here is its general form:

```java
try (resource-specification) {
   // use the resource
}
```

Typically, resource-specification is a statement that declares and initializes a resource, such as a file stream. It consists of a variable declaration in which the variable is initialized with a reference to the object being managed. When the try block ends, the resource is automatically released. In the case of a file, this means that the file is automatically closed. (Thus, there is no need to call close( ) explicitly.) Of course, this form of try can also include catch and finally clauses. This form of try is called the try-with-resources statement.

NOTE Beginning with JDK 9, it is also possible for the resource specification of the try to consist of a variable that has been declared and initialized earlier in the program. However, that variable must be **effectively final**, which means that it has not been assigned a new value after being given its initial value.

The try-with-resources statement can be used only with those resources that implement the AutoCloseable interface defined by java.lang. This interface defines the close( ) method. AutoCloseable is inherited by the Closeable interface in java.io. Both interfaces are implemented by the stream classes. Thus, try-with-resources can be used when working with streams, including file streams.

As a first example of automatically closing a file, here is a reworked version of the ShowFile program that uses it:
In the program, pay special attention to how the file is opened within the try statement:

try(FileInputStream fin = new FileInputStream(args[0])) {
    int i;

    // First, confirm that a filename has been specified.
    if(args.length != 1) {
        System.out.println("Usage: ShowFile filename");
        return;
    }

    // The following code uses a try-with-resources statement to open
    // a file and then automatically close it when the try block is left.
    try(FileInputStream fin = new FileInputStream(args[0])) {
        do {
            i = fin.read();
            if(i != -1) System.out.print((char) i);
        } while(i != -1);
    }

    } catch(OutOfResourcesException e) {
        System.out.println("File Not Found.");
    } catch(OutOfMemoryError e) {
        System.out.println("An I/O Error Occurred");
    }
}

In the program, pay special attention to how the file is opened within the try statement:

try(FileInputStream fin = new FileInputStream(args[0])) {
    int i;

    // First, confirm that a filename has been specified.
    if(args.length != 1) {
        System.out.println("Usage: ShowFile filename");
        return;
    }

    // The following code uses a try-with-resources statement to open
    // a file and then automatically close it when the try block is left.
    try(FileInputStream fin = new FileInputStream(args[0])) {
        do {
            i = fin.read();
            if(i != -1) System.out.print((char) i);
        } while(i != -1);
    }

    } catch(OutOfResourcesException e) {
        System.out.println("File Not Found.");
    } catch(OutOfMemoryError e) {
        System.out.println("An I/O Error Occurred");
    }
}

Notice how the resource-specification portion of the try declares a FileInputStream called fin, which is then assigned a reference to the file opened by its constructor. Thus, in this version of the program, the variable fin is local to the try block, being created when the try is entered. When the try is left, the stream associated with fin is
automatically closed by an implicit call to \texttt{close()}. You don’t need to call \texttt{close()} explicitly, which means that you can’t forget to close the file. This is a key advantage of using \texttt{try-with-resources}.

It is important to understand that a resource declared in the \texttt{try} statement is implicitly \texttt{final}. This means that you can’t assign to the resource after it has been created. Also, the scope of the resource is limited to the \texttt{try}-with-resources statement.

You can manage more than one resource within a single \texttt{try} statement. To do so, simply separate each resource specification with a semicolon. The following program shows an example. It reworks the \texttt{CopyFile} program shown earlier so that it uses a single \texttt{try}-with-resources statement to manage both \texttt{fin} and \texttt{fout}.

```java
/** A version of CopyFile that uses try-with-resources. It demonstrates two resources (in this case files) being managed by a single try statement. */

import java.io.*;

class CopyFile {
    public static void main(String args[]) throws IOException {
        int i;

        // First, confirm that both files have been specified.
        if(args.length != 2) {
            System.out.println("Usage: CopyFile from to");
            return;
        }

        // Open and manage two files via the try statement.
        try (FileInputStream fin = new FileInputStream(args[0]);
             FileOutputStream fout = new FileOutputStream(args[1])) {

            do {
                i = fin.read();
            }
```

In this program, notice how the input and output files are opened within the `try` block:

```java
try { 
    FileInputStream fin = new FileInputStream(args[0]);
    FileOutputStream fout = new FileOutputStream(args[1])
    // ...
}
```

After this `try` block ends, both `fin` and `fout` will have been closed. If you compare this version of the program to the previous version, you will see that it is much shorter. The ability to streamline source code is a side-benefit of automatic resource management.

There is one other aspect to `try-with-resources` that needs to be mentioned. In general, when a `try` block executes, it is possible that an exception inside the `try` block will lead to another exception that occurs when the resource is closed in a `finally` clause. In the case of a “normal” `try` statement, the original exception is lost, being preempted by the second exception. However, when using `try-with-resources`, the second exception is `suppressed`. It is not, however, lost. Instead, it is added to the list of suppressed exceptions associated with the first exception. The list of suppressed exceptions can be obtained by using the `getSuppressed()` method defined by `Throwable`.

Because of the benefits that the `try-with-resources` statement offers, it will be used by many, but not all, of the example programs in this edition of this book. Some of the examples will still use the traditional approach to closing a resource. There are several reasons for this. First, you may encounter legacy code that still relies on the traditional approach. It is important that all Java programmers be fully versed in, and comfortable with, the traditional approach when maintaining this older code. Second, it is possible that some programmers will continue to work in a pre-JDK 7 environment for a period of time. In such situations, the expanded form of `try` is not available. Finally, there may be cases in which explicitly closing a resource is more appropriate than the automated approach. For these reasons, some of the examples in this book will continue to use the traditional approach, explicitly calling `close()` . In addition to illustrating the traditional technique, these examples can also be compiled.
REMEMBER A few examples in this book use the traditional approach to closing files as a means of illustrating this technique, which is widely used in legacy code. However, for new code, you will usually want to use the automated approach supported by the `try`-with-resources statement just described.

The transient and volatile Modifiers

Java defines two interesting type modifiers: `transient` and `volatile`. These modifiers are used to handle somewhat specialized situations.

When an instance variable is declared as `transient`, its value need not persist when an object is stored. For example:

```java
class T {
    transient int a; // will not persist
    int b; // will persist
}
```

Here, if an object of type `T` is written to a persistent storage area, the contents of `a` would not be saved, but the contents of `b` would.

The `volatile` modifier tells the compiler that the variable modified by `volatile` can be changed unexpectedly by other parts of your program. One of these situations involves multithreaded programs. In a multithreaded program, sometimes two or more threads share the same variable. For efficiency considerations, each thread can keep its own, private copy of such a shared variable. The real (or master) copy of the variable is updated at various times, such as when a `synchronized` method is entered. While this approach works fine, it may be inefficient at times. In some cases, all that really matters is that the master copy of a variable always reflects its current state. To ensure this, simply specify the variable as `volatile`, which tells the compiler that it must always use the master copy of a `volatile` variable (or, at least, always keep any private copies up-to-date with the master copy, and vice versa). Also, accesses to the shared variable must be executed in the precise order indicated by the program.

Using instanceof

Sometimes, knowing the type of an object during run time is useful. For example, you might have one thread of execution that generates various types of objects, and another thread that processes these objects. In this situation, it might be useful for the
processing thread to know the type of each object when it receives it. Another situation in which knowledge of an object’s type at run time is important involves casting. In Java, an invalid cast causes a run-time error. Many invalid casts can be caught at compile time. However, casts involving class hierarchies can produce invalid casts that can be detected only at run time. For example, a superclass called A can produce two subclasses, called B and C. Thus, casting a B object into type A or casting a C object into type A is legal, but casting a B object into type C (or vice versa) isn’t legal. Because an object of type A can refer to objects of either B or C, how can you know, at run time, what type of object is actually being referred to before attempting the cast to type C? It could be an object of type A, B, or C. If it is an object of type B, a run-time exception will be thrown. Java provides the run-time operator instanceof to answer this question.

The instanceof operator has this general form:

```
objref instanceof type
```

Here, `objref` is a reference to an instance of a class, and `type` is a class type. If `objref` is of the specified type or can be cast into the specified type, then the `instanceof` operator evaluates to `true`. Otherwise, its result is `false`. Thus, `instanceof` is the means by which your program can obtain run-time type information about an object.

The following program demonstrates `instanceof`:
// Demonstrate instanceof operator.
class A {
    int i, j;
}

class B {
    int i, j;
}

class C extends A {
    int k;
}

class D extends A {
    int k;
}

class InstanceOf {
    public static void main(String args[]) {
        A a = new A();
        B b = new B();
        C c = new C();
        D d = new D();
        if (a instanceof A) {
            System.out.println("a is instance of A");
        }
        if (b instanceof B) {
            System.out.println("b is instance of B");
        }
        if (c instanceof C) {
            System.out.println("c is instance of C");
        }
        if (c instanceof A) {
            System.out.println("c can be cast to A");
        }
    }
}
```java
if(a instanceof C)
    System.out.println("a can be cast to C");

System.out.println();

// compare types of derived types
A ob;

ob = d; // A reference to d
System.out.println("ob now refers to d");
if(ob instanceof D)
    System.out.println("ob is instance of D");

System.out.println();

ob = c; // A reference to c
System.out.println("ob now refers to c");

if(ob instanceof D)
    System.out.println("ob can be cast to D");
else
    System.out.println("ob cannot be cast to D");

if(ob instanceof A)
    System.out.println("ob can be cast to A");

System.out.println();

// all objects can be cast to Object
if(a instanceof Object)
    System.out.println("a may be cast to Object");
if(b instanceof Object)
    System.out.println("b may be cast to Object");
if(c instanceof Object)
    System.out.println("c may be cast to Object");
if(d instanceof Object)
    System.out.println("d may be cast to Object");
}
```

The output from this program is shown here:
The `instanceof` operator isn’t needed by most programs, because, generally, you know the type of object with which you are working. However, it can be very useful when you’re writing generalized routines that operate on objects of a complex class hierarchy.

**strictfp**

With the creation of Java 2 several years ago, the floating-point computation model was relaxed slightly. Specifically, the new model does not require the truncation of certain intermediate values that occur during a computation. This prevents overflow or underflow in some cases. By modifying a class, a method, or interface with `strictfp`, you ensure that floating-point calculations (and thus all truncations) take place precisely as they did in earlier versions of Java. When a class is modified by `strictfp`, all the methods in the class are also modified by `strictfp` automatically.

For example, the following fragment tells Java to use the original floating-point model for calculations in all methods defined within `MyClass`:

```java
strictfp class MyClass { //...
```

Frankly, most programmers never need to use `strictfp`, because it affects only a very small class of problems.

**Native Methods**

Although it is rare, occasionally you may want to call a subroutine that is written in a
language other than Java. Typically, such a subroutine exists as executable code for the CPU and environment in which you are working—that is, native code. For example, you may want to call a native code subroutine to achieve faster execution time. Or, you may want to use a specialized, third-party library, such as a statistical package. However, because Java programs are compiled to bytecode, which is then interpreted (or compiled on-the-fly) by the Java run-time system, it would seem impossible to call a native code subroutine from within your Java program. Fortunately, this conclusion is false. Java provides the native keyword, which is used to declare native code methods. Once declared, these methods can be called from inside your Java program just as you call any other Java method. The mechanism used to integrate native code with a Java program is called the Java Native Interface (JNI).

To declare a native method, precede the method with the native modifier, but do not define any body for the method. For example:

```java
public native int meth() ;
```

After you declare a native method, you must write the native method and follow a rather complex series of steps to link it with your Java code. Consult the Java documentation for current details.

**Using assert**

Another interesting keyword is assert. It is used during program development to create an assertion, which is a condition that should be true during the execution of the program. For example, you might have a method that should always return a positive integer value. You might test this by asserting that the return value is greater than zero using an assert statement. At run time, if the condition is true, no other action takes place. However, if the condition is false, then an AssertionError is thrown. Assertions are often used during testing to verify that some expected condition is actually met. They are not usually used for released code.

The assert keyword has two forms. The first is shown here:

```java
assert condition;
```

Here, condition is an expression that must evaluate to a Boolean result. If the result is true, then the assertion is true and no other action takes place. If the condition is false, then the assertion fails and a default AssertionError object is thrown.

The second form of assert is shown here:

```java
assert condition: expr ;
```
In this version, *expr* is a value that is passed to the *AssertionError* constructor. This value is converted to its string format and displayed if an assertion fails. Typically, you will specify a string for *expr*, but any non-*void* expression is allowed as long as it defines a reasonable string conversion.

Here is an example that uses *assert*. It verifies that the return value of *getnum()* is positive.

```java
// Demonstrate assert.
class AssertDemo {
    static int val = 3;

    // Return an integer.
    static int getnum() {
        return val--;
    }

    public static void main(String args[]) {
        int n;

        for(int i=0; i < 10; i++) {
            n = getnum();

            assert n > 0; // will fail when n is 0

            System.out.println("n is " + n);
        }
    }
}
```

To enable assertion checking at run time, you must specify the -ea option. For example, to enable assertions for AssertDemo, execute it using this line:

```
java -ea AssertDemo
```

After compiling and running as just described, the program creates the following output:

```
n is 3
n is 2
n is 1
Exception in thread "main" java.lang.AssertionError
    at AssertDemo.main(AssertDemo.java:17)
```
In `main()`, repeated calls are made to the method `getnum()`, which returns an integer value. The return value of `getnum()` is assigned to `n` and then tested using this `assert` statement:

```
assert n > 0; // will fail when n is 0
```

This statement will fail when `n` equals 0, which it will after the fourth call. When this happens, an exception is thrown.

As explained, you can specify the message displayed when an assertion fails. For example, if you substitute

```
assert n > 0 : "n is not positive!";
```

for the assertion in the preceding program, then the following output will be generated:

```
   n is 3
   n is 2
   n is 1
   Exception in thread "main" java.lang.AssertionError: n is not positive!
           at AssertDemo.main(AssertDemo.java:17)
```

One important point to understand about assertions is that you must not rely on them to perform any action actually required by the program. The reason is that normally, released code will be run with assertions disabled. For example, consider this variation of the preceding program:
In this version of the program, the call to `getnum()` is moved inside the `assert` statement. Although this works fine if assertions are enabled, it will cause a malfunction when assertions are disabled, because the call to `getnum()` will never be executed! In fact, `n` must now be initialized, because the compiler will recognize that it might not be assigned a value by the `assert` statement.

Assertions can be quite useful because they streamline the type of error checking that is common during development. For example, prior to `assert`, if you wanted to verify that `n` was positive in the preceding program, you had to use a sequence of code similar to this:

```java
if (n < 0) {
    System.out.println("n is negative!");
    return; // or throw an exception
}
```

With `assert`, you need only one line of code. Furthermore, you don’t have to remove the `assert` statements from your released code.

**Assertion Enabling and Disabling Options**
When executing code, you can disable all assertions by using the -da option. You can enable or disable a specific package (and all of its subpackages) by specifying its name followed by three periods after the -ea or -da option. For example, to enable assertions in a package called MyPack, use

-ea:MyPack...

To disable assertions in MyPack, use

-da:MyPack...

You can also specify a class with the -ea or -da option. For example, this enables AssertDemo individually:

-ea:AssertDemo

**Static Import**

Java includes a feature called static import that expands the capabilities of the import keyword. By following import with the keyword static, an import statement can be used to import the static members of a class or interface. When using static import, it is possible to refer to static members directly by their names, without having to qualify them with the name of their class. This simplifies and shortens the syntax required to use a static member.

To understand the usefulness of static import, let’s begin with an example that does not use it. The following program computes the hypotenuse of a right triangle. It uses two static methods from Java’s built-in math class Math, which is part of java.lang. The first is Math.pow( ), which returns a value raised to a specified power. The second is Math.sqrt( ), which returns the square root of its argument.
Because `pow()` and `sqrt()` are static methods, they must be called through the use of their class’ name, `Math`. This results in a somewhat unwieldy hypotenuse calculation:

```java
hypot = Math.sqrt(Math.pow(side1, 2) + Math.pow(side2, 2));
```

As this simple example illustrates, having to specify the class name each time `pow()` or `sqrt()` (or any of Java’s other math methods, such as `sin()`, `cos()`, and `tan()`) is used can grow tedious.

You can eliminate the tedium of specifying the class name through the use of static import, as shown in the following version of the preceding program:
// Use static import to bring sqrt() and pow() into view.
import static java.lang.Math.sqrt;
import static java.lang.Math.pow;

// Compute the hypotenuse of a right triangle.
class Hypot {
    public static void main(String args[]) {
        double side1, side2;
        double hypot;

        side1 = 3.0;
        side2 = 4.0;

        // Here, sqrt() and pow() can be called by themselves,
        // without their class name.
        hypot = sqrt(pow(side1, 2) + pow(side2, 2));

        System.out.println("Given sides of lengths " +
                          side1 + " and " + side2 +
                          " the hypotenuse is " +
                          hypot);
    }
}

In this version, the names sqrt and pow are brought into view by these static import statements:

import static java.lang.Math.sqrt;
import static java.lang.Math.pow;

After these statements, it is no longer necessary to qualify sqrt() or pow() with their class name. Therefore, the hypotenuse calculation can more conveniently be specified, as shown here:

hypot = sqrt(pow(side1, 2) + pow(side2, 2));

As you can see, this form is considerably more readable.

There are two general forms of the import static statement. The first, which is used by the preceding example, brings into view a single name. Its general form is shown here:

import static pkg.type-name.static-member-name;

Here, type-name is the name of a class or interface that contains the desired static
member. Its full package name is specified by \textit{pkg}. The name of the member is specified by \textit{static-member-name}.

The second form of static import imports all static members of a given class or interface. Its general form is shown here:

\begin{verbatim}
import static \textit{pkg.type-name}.*;
\end{verbatim}

If you will be using many static methods or fields defined by a class, then this form lets you bring them into view without having to specify each individually. Therefore, the preceding program could have used this single \texttt{import} statement to bring both \texttt{pow()} and \texttt{sqrt()} (and \textit{all other} static members of \texttt{Math}) into view:

\begin{verbatim}
import static java.lang.Math.*;
\end{verbatim}

Of course, static import is not limited just to the \texttt{Math} class or just to methods. For example, this brings the static field \texttt{System.out} into view:

\begin{verbatim}
import static java.lang.System.out;
\end{verbatim}

After this statement, you can output to the console without having to qualify \texttt{out} with \texttt{System}, as shown here:

\begin{verbatim}
out.println("After importing System.out, you can use out directly.");
\end{verbatim}

Whether importing \texttt{System.out} as just shown is a good idea is subject to debate. Although it does shorten the statement, it is no longer instantly clear to anyone reading the program that the \texttt{out} being referred to is \texttt{System.out}.

One other point: in addition to importing the static members of classes and interfaces defined by the Java API, you can also use static import to import the static members of classes and interfaces that you create.

As convenient as static import can be, it is important not to abuse it. Remember, the reason that Java organizes its libraries into packages is to avoid namespace collisions. When you import static members, you are bringing those members into the global namespace. Thus, you are increasing the potential for namespace conflicts and for the inadvertent hiding of other names. If you are using a static member once or twice in the program, it's best not to import it. Also, some static names, such as \texttt{System.out}, are so recognizable that you might not want to import them. Static import is designed for those situations in which you are using a static member repeatedly, such as when performing a series of mathematical computations. In essence, you should use, but not abuse, this feature.
**Invoking Overloaded Constructors Through this( )**

When working with overloaded constructors, it is sometimes useful for one constructor to invoke another. In Java, this is accomplished by using another form of the `this` keyword. The general form is shown here:

```java
this(arg-list)
```

When `this()` is executed, the overloaded constructor that matches the parameter list specified by `arg-list` is executed first. Then, if there are any statements inside the original constructor, they are executed. The call to `this()` must be the first statement within the constructor.

To understand how `this()` can be used, let’s work through a short example. First, consider the following class that does not use `this()`:

```java
class MyClass {
    int a;
    int b;

    // initialize a and b individually
    MyClass(int i, int j) {
        a = i;
        b = j;
    }

    // initialize a and b to the same value
    MyClass(int i) {
        a = i;
        b = i;
    }

    // give a and b default values of 0
    MyClass() {
        a = 0;
        b = 0;
    }
}
```

This class contains three constructors, each of which initializes the values of `a` and `b`. The first is passed individual values for `a` and `b`. The second is passed just one value, which is assigned to both `a` and `b`. The third gives `a` and `b` default values of zero.
By using `this()`, it is possible to rewrite `MyClass` as shown here:

```java
class MyClass {
    int a;
    int b;

    // initialize a and b individually
    MyClass(int i, int j) {
        a = i;
        b = j;
    }

    // initialize a and b to the same value
    MyClass(int i) {
        this(i, i); // invokes MyClass(i, i)
    }

    // give a and b default values of 0
    MyClass() {
        this(0); // invokes MyClass(0)
    }
}
```

In this version of `MyClass`, the only constructor that actually assigns values to the `a` and `b` fields is `MyClass(int, int)`. The other two constructors simply invoke that constructor (either directly or indirectly) through `this()`. For example, consider what happens when this statement executes:

```java
MyClass mc = new MyClass(8);
```

The call to `MyClass(8)` causes `this(8, 8)` to be executed, which translates into a call to `MyClass(8, 8)`, because this is the version of the `MyClass` constructor whose parameter list matches the arguments passed via `this()`. Now, consider the following statement, which uses the default constructor:

```java
MyClass mc2 = new MyClass();
```

In this case, `this(0)` is called. This causes `MyClass(0)` to be invoked because it is the constructor with the matching parameter list. Of course, `MyClass(0)` then calls `MyClass(0,0)` as just described.

One reason why invoking overloaded constructors through `this()` can be useful is that it can prevent the unnecessary duplication of code. In many cases, reducing duplicate code decreases the time it takes to load your class because often the object
code is smaller. This is especially important for programs delivered via the Internet in which load times are an issue. Using `this()` can also help structure your code when constructors contain a large amount of duplicate code.

However, you need to be careful. Constructors that call `this()` will execute a bit slower than those that contain all of their initialization code inline. This is because the call and return mechanism used when the second constructor is invoked adds overhead. If your class will be used to create only a handful of objects, or if the constructors in the class that call `this()` will be seldom used, then this decrease in run-time performance is probably insignificant. However, if your class will be used to create a large number of objects (on the order of thousands) during program execution, then the negative impact of the increased overhead could be meaningful. Because object creation affects all users of your class, there will be cases in which you must carefully weigh the benefits of faster load time against the increased time it takes to create an object.

Here is another consideration: for very short constructors, such as those used by `MyClass`, there is often little difference in the size of the object code whether `this()` is used or not. (Actually, there are cases in which no reduction in the size of the object code is achieved.) This is because the bytecode that sets up and returns from the call to `this()` adds instructions to the object file. Therefore, in these types of situations, even though duplicate code is eliminated, using `this()` will not obtain significant savings in terms of load time. However, the added cost in terms of overhead to each object’s construction will still be incurred. Therefore, `this()` is most applicable to constructors that contain large amounts of initialization code, not those that simply set the value of a handful of fields.

There are two restrictions you need to keep in mind when using `this()`. First, you cannot use any instance variable of the constructor’s class in a call to `this()`. Second, you cannot use `super()` and `this()` in the same constructor because each must be the first statement in the constructor.

A Word About Compact API Profiles

JDK 8 added a feature that organizes subsets of the API library into what are called compact profiles. These are called `compact1`, `compact2`, and `compact3`. Each profile contains a subset of the library. Furthermore, `compact2` includes all of `compact1`, and `compact3` includes all of `compact2`. Thus, each profile builds on the previous one. The advantage of the compact profiles is that an application that does not require the full library need not download it. Using a compact profile reduces the size of the library, thus enabling some types of Java applications to run on devices that could not otherwise support the entire Java API. The use of a compact profile
can also reduce the time it takes to load a program. The JDK 8 API documentation indicates to which (if any) profile each API element belongs. It is important to emphasize that the new modules feature added by JDK 9 supersedes compact profiles.
CHAPTER
Since the original 1.0 release in 1995, many new features have been added to Java. One that has had a profound and long-lasting impact is generics. Introduced by JDK 5, generics changed Java in two important ways. First, it added a new syntactical element to the language. Second, it caused changes to many of the classes and methods in the core API. Today, generics are an integral part of Java programming, and a solid understanding of this important feature is required. It is examined here in detail.

Through the use of generics, it is possible to create classes, interfaces, and methods that will work in a type-safe manner with various kinds of data. Many algorithms are logically the same no matter what type of data they are being applied to. For example, the mechanism that supports a stack is the same whether that stack is storing items of type `Integer`, `String`, `Object`, or `Thread`. With generics, you can define an algorithm once, independently of any specific type of data, and then apply that algorithm to a wide variety of data types without any additional effort. The expressive power generics added to the language fundamentally changed the way that Java code is written.

Perhaps the one feature of Java that has been most significantly affected by generics is the Collections Framework. The Collections Framework is part of the Java API and is described in detail in Chapter 19, but a brief mention is useful now. A collection is a group of objects. The Collections Framework defines several classes, such as lists and maps, that manage collections. The collection classes have always been able to work with any type of object. The benefit that generics added is that the collection classes can now be used with complete type safety. Thus, in addition to being a powerful language element on its own, generics also enabled an existing feature to be substantially improved. This is another reason why generics were such an important addition to Java.

This chapter describes the syntax, theory, and use of generics. It also shows how generics provide type safety for some previously difficult cases. Once you have completed this chapter, you will want to examine Chapter 19, which covers the Collections Framework. There you will find many examples of generics at work.

What Are Generics?
At its core, the term **generics** means *parameterized types*. Parameterized types are important because they enable you to create classes, interfaces, and methods in which the type of data upon which they operate is specified as a parameter. Using generics, it is possible to create a single class, for example, that automatically works with different types of data. A class, interface, or method that operates on a parameterized type is called *generic*, as in *generic class* or *generic method*.

It is important to understand that Java has always given you the ability to create generalized classes, interfaces, and methods by operating through references of type `Object`. Because `Object` is the superclass of all other classes, an `Object` reference can refer to any type object. Thus, in pre-generics code, generalized classes, interfaces, and methods used `Object` references to operate on various types of objects. The problem was that they could not do so with type safety.

Generics added the type safety that was lacking. They also streamlined the process, because it is no longer necessary to explicitly employ casts to translate between `Object` and the type of data that is actually being operated upon. With generics, all casts are automatic and implicit. Thus, generics expanded your ability to reuse code and let you do so safely and easily.

**CAUTION A Warning to C++ Programmers:** Although generics are similar to templates in C++, they are not the same. There are some fundamental differences between the two approaches to generic types. If you have a background in C++, it is important not to jump to conclusions about how generics work in Java.

**A Simple Generics Example**

Let’s begin with a simple example of a generic class. The following program defines two classes. The first is the generic class **Gen**, and the second is **GenDemo**, which uses **Gen**.
// A simple generic class.
// Here, T is a type parameter that
// will be replaced by a real type
// when an object of type Gen is created.
class Gen<T> {
    T ob; // declare an object of type T

    // Pass the constructor a reference to
    // an object of type T.
    Gen(T o) {
        ob = o;
    }

    // Return ob.
    T getob() {
        return ob;
    }

    // Show type of T.
void showType() {
    System.out.println("Type of T is "+
            ob.getClass().getName());
}

// Demonstrate the generic class.
class GenDemo {
    public static void main(String args[]) {
        // Create a Gen reference for Integers.
        Gen<Integer> iOb;

        // Create a Gen<Integer> object and assign its
        // reference to iOb. Notice the use of autoboxing
        // to encapsulate the value 88 within an Integer object.
        iOb = new Gen<Integer>(88);

        // Show the type of data used by iOb.
        iOb.showType();

        // Get the value in iOb. Notice that
        // no cast is needed.
        int v = iOb.getob();
        System.out.println("value: "+v);
        System.out.println();

        // Create a Gen object for Strings.
        Gen<String> strOb = new Gen<String>("Generics Test");

        // Show the type of data used by strOb.
        strOb.showType();

        // Get the value of strOb. Again, notice
        // that no cast is needed.
        String str = strOb.getob();
        System.out.println("value: "+str);
    }
}

The output produced by the program is shown here:
Let's examine this program carefully.

    First, notice how **Gen** is declared by the following line:

    ```java
    class Gen<T> {
    }
    ```

    Here, **T** is the name of a *type parameter*. This name is used as a placeholder for the actual type that will be passed to **Gen** when an object is created. Thus, **T** is used within **Gen** whenever the type parameter is needed. Notice that **T** is contained within `< >`. This syntax can be generalized. Whenever a type parameter is being declared, it is specified within angle brackets. Because **Gen** uses a type parameter, **Gen** is a generic class, which is also called a *parameterized type*.

    Next, **T** is used to declare an object called **ob**, as shown here:

    ```java
    T ob; // declare an object of type T
    ```

    As explained, **T** is a placeholder for the actual type that will be specified when a **Gen** object is created. Thus, **ob** will be an object of the type passed to **T**. For example, if type **String** is passed to **T**, then in that instance, **ob** will be of type **String**.

    Now consider **Gen**'s constructor:

    ```java
    Gen(T o) {
      ob = o;
    }
    ```

    Notice that its parameter, **o**, is of type **T**. This means that the actual type of **o** is determined by the type passed to **T** when a **Gen** object is created. Also, because both the parameter **o** and the member variable **ob** are of type **T**, they will both be of the same actual type when a **Gen** object is created.

    The type parameter **T** can also be used to specify the return type of a method, as is the case with the **getob( )** method, shown here:

    ```java
    T getob() {
      return ob;
    }
    ```

    Because **ob** is also of type **T**, its type is compatible with the return type specified by
The `showType()` method displays the type of T by calling `getName()` on the `Class` object returned by the call to `getClass()` on `ob`. The `getClass()` method is defined by `Object` and is thus a member of all class types. It returns a `Class` object that corresponds to the type of the class of the object on which it is called. `Class` defines the `getName()` method, which returns a string representation of the class name.

The `GenDemo` class demonstrates the generic `Gen` class. It first creates a version of `Gen` for integers, as shown here:

```java
Gen<Integer> iOb;
```

Look closely at this declaration. First, notice that the type `Integer` is specified within the angle brackets after `Gen`. In this case, `Integer` is a type argument that is passed to `Gen`'s type parameter, T. This effectively creates a version of `Gen` in which all references to T are translated into references to `Integer`. Thus, for this declaration, `ob` is of type `Integer`, and the return type of `getob()` is of type `Integer`.

Before moving on, it’s necessary to state that the Java compiler does not actually create different versions of `Gen`, or of any other generic class. Although it’s helpful to think in these terms, it is not what actually happens. Instead, the compiler removes all generic type information, substituting the necessary casts, to make your code behave as if a specific version of `Gen` were created. Thus, there is really only one version of `Gen` that actually exists in your program. The process of removing generic type information is called erasure, and we will return to this topic later in this chapter.

The next line assigns to `iOb` a reference to an instance of an `Integer` version of the `Gen` class:

```java
iOb = new Gen<Integer>(88);
```

Notice that when the `Gen` constructor is called, the type argument `Integer` is also specified. This is because the type of the object (in this case `iOb`) to which the reference is being assigned is of type `Gen<Integer>`. Thus, the reference returned by `new` must also be of type `Gen<Integer>`. If it isn’t, a compile-time error will result. For example, the following assignment will cause a compile-time error:

```java
iOb = new Gen<Double>(88.0); // Error!
```

Because `iOb` is of type `Gen<Integer>`, it can’t be used to refer to an object of `Gen<Double>`. This type checking is one of the main benefits of generics because it ensures type safety.
NOTE As you will see later in this chapter, it is possible to shorten the syntax used to create an instance of a generic class. In the interest of clarity, we will use the full syntax at this time.

As the comments in the program state, the assignment

```java
iOb = new Gen<Integer>(88);
```

makes use of autoboxing to encapsulate the value 88, which is an `int`, into an `Integer`. This works because `Gen<Integer>` creates a constructor that takes an `Integer` argument. Because an `Integer` is expected, Java will automatically box 88 inside one. Of course, the assignment could also have been written explicitly, like this:

```java
iOb = new Gen<Integer>(Integer.valueOf(88));
```

However, there would be no benefit to using this version.

The program then displays the type of `ob` within `iOb`, which is `Integer`. Next, the program obtains the value of `ob` by use of the following line:

```java
int v = iOb.getob();
```

Because the return type of `getob()` is `T`, which was replaced by `Integer` when `iOb` was declared, the return type of `getob()` is also `Integer`, which unboxes into `int` when assigned to `v` (which is an `int`). Thus, there is no need to cast the return type of `getob()` to `Integer`. Of course, it’s not necessary to use the auto-unboxing feature. The preceding line could have been written like this, too:

```java
int v = iOb.getob().intValue();
```

However, the auto-unboxing feature makes the code more compact.

Next, `GenDemo` declares an object of type `Gen<String>`:

```java
Gen<String> strOb = new Gen<String>("Generics Test");
```

Because the type argument is `String`, `String` is substituted for `T` inside `Gen`. This creates (conceptually) a `String` version of `Gen`, as the remaining lines in the program demonstrate.

**Generics Work Only with Reference Types**

When declaring an instance of a generic type, the type argument passed to the type parameter must be a reference type. You cannot use a primitive type, such as `int` or
For example, with \texttt{Gen}, it is possible to pass any class type to \texttt{T}, but you cannot pass a primitive type to a type parameter. Therefore, the following declaration is illegal:

\begin{verbatim}
Gen<int> intOb = new Gen<int>(53); // Error, can't use primitive type
\end{verbatim}

Of course, not being able to specify a primitive type is not a serious restriction because you can use the type wrappers (as the preceding example did) to encapsulate a primitive type. Further, Java’s autoboxing and auto-unboxing mechanism makes the use of the type wrapper transparent.

**Generic Types Differ Based on Their Type Arguments**

A key point to understand about generic types is that a reference of one specific version of a generic type is not type compatible with another version of the same generic type. For example, assuming the program just shown, the following line of code is in error and will not compile:

\begin{verbatim}
iOb = strOb; // Wrong!
\end{verbatim}

Even though both \texttt{iOb} and \texttt{strOb} are of type \texttt{Gen<T>}, they are references to different types because their type arguments differ. This is part of the way that generics add type safety and prevent errors.

**How Generics Improve Type Safety**

At this point, you might be asking yourself the following question: Given that the same functionality found in the generic \texttt{Gen} class can be achieved without generics, by simply specifying \texttt{Object} as the data type and employing the proper casts, what is the benefit of making \texttt{Gen} generic? The answer is that generics automatically ensure the type safety of all operations involving \texttt{Gen}. In the process, they eliminate the need for you to enter casts and to type-check code by hand.

To understand the benefits of generics, first consider the following program that creates a non-generic equivalent of \texttt{Gen}:
// NonGen is functionally equivalent to Gen
// but does not use generics.
class NonGen {
    Object ob; // ob is now of type Object

    // Pass the constructor a reference to
    // an object of type Object
    NonGen(Object o) {
        ob = o;
    }

    // Return type Object.
    Object getob() {
        return ob;
    }

    // Show type of ob.
    void showType() {
        System.out.println("Type of ob is "+
                        ob.getClass().getName());
    }
}

// Demonstrate the non-generic class.
class NonGenDemo {
    public static void main(String args[]) {
        NonGen iOb;
There are several things of interest in this version. First, notice that `NonGen` replaces all uses of `T` with `Object`. This makes `NonGen` able to store any type of object, as can the generic version. However, it also prevents the Java compiler from having any real knowledge about the type of data actually stored in `NonGen`, which is bad for two reasons. First, explicit casts must be employed to retrieve the stored data. Second, many kinds of type mismatch errors cannot be found until run time. Let’s look closely at each problem.

Notice this line:

```java
int v = (Integer) iOb.getob();
```
Because the return type of `getob()` is `Object`, the cast to `Integer` is necessary to enable that value to be auto-unboxed and stored in `v`. If you remove the cast, the program will not compile. With the generic version, this cast was implicit. In the non-generic version, the cast must be explicit. This is not only an inconvenience, but also a potential source of error.

Now, consider the following sequence from near the end of the program:

```java
// This compiles, but is conceptually wrong!
iOb = strOb;
v = (Integer) iOb.getob(); // run-time error!
```

Here, `strOb` is assigned to `iOb`. However, `strOb` refers to an object that contains a string, not an integer. This assignment is syntactically valid because all `NonGen` references are the same, and any `NonGen` reference can refer to any other `NonGen` object. However, the statement is semantically wrong, as the next line shows. Here, the return type of `getob()` is cast to `Integer`, and then an attempt is made to assign this value to `v`. The trouble is that `iOb` now refers to an object that stores a `String`, not an `Integer`. Unfortunately, without the use of generics, the Java compiler has no way to know this. Instead, a run-time exception occurs when the cast to `Integer` is attempted. As you know, it is extremely bad to have run-time exceptions occur in your code!

The preceding sequence can’t occur when generics are used. If this sequence were attempted in the generic version of the program, the compiler would catch it and report an error, thus preventing a serious bug that results in a run-time exception. The ability to create type-safe code in which type-mismatch errors are caught at compile time is a key advantage of generics. Although using `Object` references to create “generic” code has always been possible, that code was not type safe, and its misuse could result in run-time exceptions. Generics prevent this from occurring. In essence, through generics, run-time errors are converted into compile-time errors. This is a major advantage.

**A Generic Class with Two Type Parameters**

You can declare more than one type parameter in a generic type. To specify two or more type parameters, simply use a comma-separated list. For example, the following `TwoGen` class is a variation of the `Gen` class that has two type parameters:
// A simple generic class with two type
// parameters: T and V.
class TwoGen<T, V> {
    T ob1;
    V ob2;

    // Pass the constructor a reference to
    // an object of type T and an object of type V.
    TwoGen(T o1, V o2) {
        ob1 = o1;
        ob2 = o2;
    }

    // Show types of T and V.
    void showTypes() {
        System.out.println("Type of T is "+
                          ob1.getClass().getName());

        System.out.println("Type of V is "+
                          ob2.getClass().getName());
    }

    T getob1() {
        return ob1;
    }
}
V getob2() {
    return ob2;
}

// Demonstrate TwoGen.
class SimpGen {
    public static void main(String args[]) {

        TwoGen<Integer, String> tgObj =
            new TwoGen<Integer, String>(88, "Generics");

        // Show the types.
        tgObj.showTypes();

        // Obtain and show values.
        int v = tgObj.getob1();
        System.out.println("value: "+v);

        String str = tgObj.getob2();
        System.out.println("value: "+str);
    }
}

The output from this program is shown here:

Type of T is java.lang.Integer
Type of V is java.lang.String
value: 88
value: Generics

Notice how TwoGen is declared:

class TwoGen<T, V> {

It specifies two type parameters: T and V, separated by a comma. Because it has two type parameters, two type arguments must be passed to TwoGen when an object is created, as shown next:

TwoGen<Integer, String> tgObj =
    new TwoGen<Integer, String>(88, "Generics");

In this case, Integer is substituted for T, and String is substituted for V.
Although the two type arguments differ in this example, it is possible for both types to be the same. For example, the following line of code is valid:
In this case, both $T$ and $V$ would be of type `String`. Of course, if the type arguments were always the same, then two type parameters would be unnecessary.

**The General Form of a Generic Class**

The generics syntax shown in the preceding examples can be generalized. Here is the syntax for declaring a generic class:

```
class class-name<type-param-list> { // …
```

Here is the full syntax for declaring a reference to a generic class and instance creation:

```
class-name<type-arg-list> var-name =
    new class-name<type-arg-list>(cons-arg-list);
```

**Bounded Types**

In the preceding examples, the type parameters could be replaced by any class type. This is fine for many purposes, but sometimes it is useful to limit the types that can be passed to a type parameter. For example, assume that you want to create a generic class that contains a method that returns the average of an array of numbers. Furthermore, you want to use the class to obtain the average of an array of any type of number, including integers, `floats`, and `doubles`. Thus, you want to specify the type of the numbers generically, using a type parameter. To create such a class, you might try something like this:

```java
TwoGen<String, String> x = new TwoGen<String, String> ("A", "B");
```
In Stats, the average() method attempts to obtain the double version of each number in the nums array by calling doubleValue(). Because all numeric classes, such as Integer and Double, are subclasses of Number, and Number defines the doubleValue() method, this method is available to all numeric wrapper classes. The trouble is that the compiler has no way to know that you are intending to create Stats objects using only numeric types. Thus, when you try to compile Stats, an error is reported that indicates that the doubleValue() method is unknown. To solve this problem, you need some way to tell the compiler that you intend to pass only numeric types to T. Furthermore, you need some way to ensure that only numeric types are actually passed.

To handle such situations, Java provides bounded types. When specifying a type parameter, you can create an upper bound that declares the superclass from which all type arguments must be derived. This is accomplished through the use of an extends clause when specifying the type parameter, as shown here:

<T extends superclass>
This specifies that $T$ can only be replaced by `superclass`, or subclasses of `superclass`. Thus, `superclass` defines an inclusive, upper limit.

You can use an upper bound to fix the `Stats` class shown earlier by specifying `Number` as an upper bound, as shown here:

```java
// In this version of Stats, the type argument for
// T must be either Number, or a class derived
// from Number.
class Stats<T extends Number> {
    T[] nums; // array of Number or subclass

    // Pass the constructor a reference to
    // an array of type Number or subclass.
    Stats(T[] o) {
        nums = o;
    }

    // Return type double in all cases.
    double average() {
        double sum = 0.0;

        for(int i=0; i < nums.length; i++)
            sum += nums[i].doubleValue();

        return sum / nums.length;
    }
}

// Demonstrate Stats.
class BoundsDemo {
    public static void main(String args[]) {
```
Notice how Stats is now declared by this line:

class Stats<T extends Number> {

Because the type T is now bounded by Number, the Java compiler knows that all objects of type T can call doubleValue( ) because it is a method declared by Number. This is, by itself, a major advantage. However, as an added bonus, the bounding of T also prevents nonnumeric Stats objects from being created. For example, if you try removing the comments from the lines at the end of the program, and then try recompiling, you will receive compile-time errors because String is not a subclass of Number.

In addition to using a class type as a bound, you can also use an interface type. In fact, you can specify multiple interfaces as bounds. Furthermore, a bound can include both a class type and one or more interfaces. In this case, the class type must be specified first. When a bound includes an interface type, only type arguments that implement that interface are legal. When specifying a bound that has a class and an interface, or multiple interfaces, use the & operator to connect them. For example,
class Gen<T extends MyClass & MyInterface> { // ... 

Here, T is bounded by a class called MyClass and an interface called MyInterface. Thus, any type argument passed to T must be a subclass of MyClass and implement MyInterface.

Using Wildcard Arguments

As useful as type safety is, sometimes it can get in the way of perfectly acceptable constructs. For example, given the Stats class shown at the end of the preceding section, assume that you want to add a method called sameAvg() that determines if two Stats objects contain arrays that yield the same average, no matter what type of numeric data each object holds. For example, if one object contains the double values 1.0, 2.0, and 3.0, and the other object contains the integer values 2, 1, and 3, then the averages will be the same. One way to implement sameAvg() is to pass it a Stats argument, and then compare the average of that argument against the invoking object, returning true only if the averages are the same. For example, you want to be able to call sameAvg(), as shown here:

```java
Integer inums[] = { 1, 2, 3, 4, 5 };
Double dnums[] = { 1.1, 2.2, 3.3, 4.4, 5.5 };

Stats<Integer> iob = new Stats<Integer>(inums);
Stats<Double> dob = new Stats<Double>(dnums);

if(iob.sameAvg(dob))
    System.out.println("Averages are the same.");
else
    System.out.println("Averages differ.");
```

At first, creating sameAvg() seems like an easy problem. Because Stats is generic and its average() method can work on any type of Stats object, it seems that creating sameAvg() would be straightforward. Unfortunately, trouble starts as soon as you try to declare a parameter of type Stats. Because Stats is a parameterized type, what do you specify for Stats’ type parameter when you declare a parameter of that type?

At first, you might think of a solution like this, in which T is used as the type parameter:
The trouble with this attempt is that it will work only with other Stats objects whose type is the same as the invoking object. For example, if the invoking object is of type Stats<Integer>, then the parameter ob must also be of type Stats<Integer>. It can’t be used to compare the average of an object of type Stats<Double> with the average of an object of type Stats<Short>, for example. Therefore, this approach won’t work except in a very narrow context and does not yield a general (that is, generic) solution.

To create a generic sameAvg() method, you must use another feature of Java generics: the wildcard argument. The wildcard argument is specified by the ?, and it represents an unknown type. Using a wildcard, here is one way to write the sameAvg() method:

```java
// Determine if two averages are the same.
// Notice the use of the wildcard.
boolean sameAvg(Stats<?> ob) {
    if(average() == ob.average())
        return true;

    return false;
}
```

Here, Stats<?> matches any Stats object, allowing any two Stats objects to have their averages compared. The following program demonstrates this:
// Use a wildcard.
class Stats<T extends Number> {
    T[] nums; // array of Number or subclass

    // Pass the constructor a reference to
    // an array of type Number or subclass.
    Stats(T[] o) {
        nums = o;
    }

    // Return type double in all cases.
    double average() {
        double sum = 0.0;
        for(int i=0; i < nums.length; i++)
            sum += nums[i].doubleValue();
        return sum / nums.length;
    }

    // Determine if two averages are the same.
    // Notice the use of the wildcard.
    boolean sameAvg(Stats<?> ob) {
        if(average() == ob.average())
            return true;
        return false;
    }
}

// Demonstrate wildcard.
class WildcardDemo {
    public static void main(String args[]) {
        Integer inums[] = { 1, 2, 3, 4, 5 };
        Stats<Integer> iob = new Stats<Integer>(inums);
        double v = iob.average();
        System.out.println("iob average is " + v);

        Double dnums[] = { 1.1, 2.2, 3.3, 4.4, 5.5 };
        Stats<Double> dob = new Stats<Double>(dnums);
        double w = dob.average();
        System.out.println("dob average is " + w);
    }
}
The output is shown here:

iob average is 3.0
dob average is 3.3
fob average is 3.0
Averages of iob and dob differ.
Averages of iob and fob are the same.

One last point: It is important to understand that the wildcard does not affect what type of Stats objects can be created. This is governed by the extends clause in the Stats declaration. The wildcard simply matches any valid Stats object.

**Bounded Wildcards**

Wildcard arguments can be bounded in much the same way that a type parameter can be bounded. A bounded wildcard is especially important when you are creating a generic type that will operate on a class hierarchy. To understand why, let’s work through an example. Consider the following hierarchy of classes that encapsulate coordinates:
At the top of the hierarchy is TwoD, which encapsulates a two-dimensional, XY coordinate. TwoD is inherited by ThreeD, which adds a third dimension, creating an XYZ coordinate. ThreeD is inherited by FourD, which adds a fourth dimension (time), yielding a four-dimensional coordinate.

Shown next is a generic class called Coords, which stores an array of coordinates:

```java
// This class holds an array of coordinate objects.
class Coords<T extends TwoD> {
    T[] coords;

    Coords(T[] o) { coords = o; }
}
```
Notice that `Coords` specifies a type parameter bounded by `TwoD`. This means that any array stored in a `Coords` object will contain objects of type `TwoD` or one of its subclasses.

Now, assume that you want to write a method that displays the X and Y coordinates for each element in the `coords` array of a `Coords` object. Because all types of `Coords` objects have at least two coordinates (X and Y), this is easy to do using a wildcard, as shown here:

```java
static void showXY(Coords<?> c) {
    System.out.println("X Y Coordinates:");
    for(int i=0; i < c.coords.length; i++)
        System.out.println(c.coords[i].x + " " + c.coords[i].y);
    System.out.println();
}
```

Because `Coords` is a bounded generic type that specifies `TwoD` as an upper bound, all objects that can be used to create a `Coords` object will be arrays of type `TwoD`, or of classes derived from `TwoD`. Thus, `showXY()` can display the contents of any `Coords` object.

However, what if you want to create a method that displays the X, Y, and Z coordinates of a `ThreeD` or `FourD` object? The trouble is that not all `Coords` objects will have three coordinates, because a `Coords<TwoD>` object will only have X and Y. Therefore, how do you write a method that displays the X, Y, and Z coordinates for `Coords<ThreeD>` and `Coords<FourD>` objects, while preventing that method from being used with `Coords<TwoD>` objects? The answer is the **bounded wildcard argument**.

A bounded wildcard specifies either an upper bound or a lower bound for the type argument. This enables you to restrict the types of objects upon which a method will operate. The most common bounded wildcard is the upper bound, which is created using an `extends` clause in much the same way it is used to create a bounded type.

Using a bounded wildcard, it is easy to create a method that displays the X, Y, and Z coordinates of a `Coords` object, if that object actually has those three coordinates. For example, the following `showXYZ()` method shows the X, Y, and Z coordinates of the elements stored in a `Coords` object, if those elements are actually of type `ThreeD` (or are derived from `ThreeD`):
Notice that an `extends` clause has been added to the wildcard in the declaration of parameter `c`. It states that the `?` can match any type as long as it is `ThreeD`, or a class derived from `ThreeD`. Thus, the `extends` clause establishes an upper bound that the `?` can match. Because of this bound, `showXYZ( )` can be called with references to objects of type `Coords<ThreeD>` or `Coords<FourD>`, but not with a reference of type `Coords<TwoD>`. Attempting to call `showXZY( )` with a `Coords<TwoD>` reference results in a compile-time error, thus ensuring type safety.

Here is an entire program that demonstrates the actions of a bounded wildcard argument:

```java
static void showXYZ(Coords<? extends ThreeD> c) {
    System.out.println("X Y Z Coordinates:");
    for(int i=0; i < c.coords.length; i++)
        System.out.println(c.coords[i].x + " " +
                            c.coords[i].y + " " +
                            c.coords[i].z);
    System.out.println();
}
```
// Bounded Wildcard arguments.

// Two-dimensional coordinates.
class TwoD {
    int x, y;

    TwoD(int a, int b) {
        x = a;
        y = b;
    }
}

// Three-dimensional coordinates.
class ThreeD extends TwoD {
    int z;

    ThreeD(int a, int b, int c) {
        super(a, b);
        z = c;
    }
}

// Four-dimensional coordinates.
class FourD extends ThreeD {
    int t;
FourD(int a, int b, int c, int d) {
    super(a, b, c);
    t = d;
}

// This class holds an array of coordinate objects.
class Coords<T extends TwoD> {
    T[] coords;
    
    Coords(T[] o) { coords = o; }
}

// Demonstrate a bounded wildcard.
class BoundedWildcard {
    static void showXY(Coords<? c) {
        System.out.println("X Y Coordinates:");
        for(int i=0; i < c.coords.length; i++)
            System.out.println(c.coords[i].x + " " + c.coords[i].y);
        System.out.println();
    }

    static void showXYZ(Coords<? extends ThreeD> c) {
        System.out.println("X Y Z Coordinates:");
        for(int i=0; i < c.coords.length; i++)
System.out.println(c.coords[i].x + " " +
    c.coords[i].y + " " +
    c.coords[i].z);
System.out.println();
}

static void showAll(Coords<? extends FourD> c) {
    System.out.println("X Y Z T Coordinates:");
    for (int i = 0; i < c.coords.length; i++)
        System.out.println(c.coords[i].x + " " +
                            c.coords[i].y + " " +
                            c.coords[i].z + " " +
                            c.coords[i].t);
    System.out.println();
}

public static void main(String args[]) {
    TwoD td[] = {
        new TwoD(0, 0),
        new TwoD(7, 9),
        new TwoD(18, 4),
        new TwoD(-1, -23)
    };

    Coords<TwoD> tdlocs = new Coords<TwoD>(td);
The output from the program is shown here:

Contents of tdlocs.
X Y Coordinates:
0 0
Because `tdlocs` is a `Coords(TwoD)` object, it cannot be used to call `showXYZ()` or `showAll()` because bounded wildcard arguments in their declarations prevent it. To prove this to yourself, try removing the comment symbols, and then attempt to compile the program. You will receive compilation errors because of the type mismatches.

In general, to establish an upper bound for a wildcard, use the following type of wildcard expression:

```java
<? extends superclass>
```

where `superclass` is the name of the class that serves as the upper bound. Remember, this is an inclusive clause because the class forming the upper bound (that is, specified by `superclass`) is also within bounds.

You can also specify a lower bound for a wildcard by adding a `super` clause to a wildcard declaration. Here is its general form:
In this case, only classes that are superclasses of `subclass` are acceptable arguments. This is an inclusive clause.

**Creating a Generic Method**

As the preceding examples have shown, methods inside a generic class can make use of a class’ type parameter and are, therefore, automatically generic relative to the type parameter. However, it is possible to declare a generic method that uses one or more type parameters of its own. Furthermore, it is possible to create a generic method that is enclosed within a non-generic class.

Let’s begin with an example. The following program declares a non-generic class called `GenMethDemo` and a static generic method within that class called `isIn()`. The `isIn()` method determines if an object is a member of an array. It can be used with any type of object and array as long as the array contains objects that are compatible with the type of the object being sought.
The output from the program is shown here:
Let's examine `isIn()` closely. First, notice how it is declared by this line:

```java
static <T extends Comparable<T>, V extends T> boolean isIn(T x, V[] y) { ...
```

The type parameters are declared before the return type of the method. Also note that `T` extends `Comparable<T>`. `Comparable` is an interface declared in `java.lang`. A class that implements `Comparable` defines objects that can be ordered. Thus, requiring an upper bound of `Comparable` ensures that `isIn()` can be used only with objects that are capable of being compared. `Comparable` is generic, and its type parameter specifies the type of objects that it compares. (Shortly, you will see how to create a generic interface.) Next, notice that the type `V` is upper-bounded by `T`. Thus, `V` must either be the same as type `T`, or a subclass of `T`. This relationship enforces that `isIn()` can be called only with arguments that are compatible with each other. Also notice that `isIn()` is static, enabling it to be called independently of any object. Understand, though, that generic methods can be either static or non-static. There is no restriction in this regard.

Now, notice how `isIn()` is called within `main()` by use of the normal call syntax, without the need to specify type arguments. This is because the types of the arguments are automatically discerned, and the types of `T` and `V` are adjusted accordingly. For example, in the first call:

```java
if(isIn(2, nums))
```

the type of the first argument is `Integer` (due to autoboxing), which causes `Integer` to be substituted for `T`. The base type of the second argument is also `Integer`, which makes `Integer` a substitute for `V`, too. In the second call, `String` types are used, and the types of `T` and `V` are replaced by `String`.

Although type inference will be sufficient for most generic method calls, you can explicitly specify the type argument if needed. For example, here is how the first call to `isIn()` looks when the type arguments are specified:

```java
GenMethDemo.<Integer, Integer>isIn(2, nums)
```

Of course, in this case, there is nothing gained by specifying the type arguments. Furthermore, JDK 8 improved type inference as it relates to methods. As a result, there are fewer cases in which explicit type arguments are needed.

Now, notice the commented-out code, shown here:
If you remove the comments and then try to compile the program, you will receive an error. The reason is that the type parameter V is bounded by T in the extends clause in V’s declaration. This means that V must be either type T, or a subclass of T. In this case, the first argument is of type String, making T into String, but the second argument is of type Integer, which is not a subclass of String. This causes a compile-time type-mismatch error. This ability to enforce type safety is one of the most important advantages of generic methods.

The syntax used to create isIn() can be generalized. Here is the syntax for a generic method:

```java
<type-param-list> ret-type meth-name (param-list) { // …
```

In all cases, type-param-list is a comma-separated list of type parameters. Notice that for a generic method, the type parameter list precedes the return type.

**Generic Constructors**

It is possible for constructors to be generic, even if their class is not. For example, consider the following short program:
// Use a generic constructor.
class GenCons {
    private double val;

    <T extends Number> GenCons(T arg) {
        val = arg.doubleValue();
    }

    void showval() {
        System.out.println("val: " + val);
    }
}

class GenConsDemo {
    public static void main(String args[]) {
        GenCons test = new GenCons(100);
        GenCons test2 = new GenCons(123.5F);

        test.showval();
        test2.showval();
    }
}

The output is shown here:
val: 100.0
val: 123.5

Because GenCons() specifies a parameter of a generic type, which must be a subclass of Number, GenCons() can be called with any numeric type, including Integer, Float, or Double. Therefore, even though GenCons is not a generic class, its constructor is generic.

**Generic Interfaces**

In addition to generic classes and methods, you can also have generic interfaces. Generic interfaces are specified just like generic classes. Here is an example. It creates an interface called MinMax that declares the methods min() and max(), which are expected to return the minimum and maximum value of some set of objects.
// A generic interface example.

// A Min/Max interface.
interface MinMax<T extends Comparable<T>> {
    T min();
    T max();
}

// Now, implement MinMax
class MyClass<T extends Comparable<T>> implements MinMax<T> {
    T[] vals;

    MyClass(T[] o) { vals = o; }

    // Return the minimum value in vals.
    public T min() {
        T v = vals[0];

        for(int i=1; i < vals.length; i++)
            if(vals[i].compareTo(v) < 0) v = vals[i];

        return v;
    }
}
The output is shown here:

Max value in inums: 8
Min value in inums: 2
Max value in chs: w
Min value in chs: b

Although most aspects of this program should be easy to understand, a couple of key points need to be made. First, notice that MinMax is declared like this:

interface MinMax<T extends Comparable<T>> {

In general, a generic interface is declared in the same way as is a generic class. In this case, the type parameter is T, and its upper bound is Comparable. As explained earlier, Comparable is an interface defined by java.lang that specifies how objects are compared. Its type parameter specifies the type of the objects being compared.

Next, MinMax is implemented by MyClass. Notice the declaration of MyClass, shown here:
Pay special attention to the way that the type parameter T is declared by MyClass and then passed to MinMax. Because MinMax requires a type that implements Comparable, the implementing class (MyClass in this case) must specify the same bound. Furthermore, once this bound has been established, there is no need to specify it again in the implements clause. In fact, it would be wrong to do so. For example, this line is incorrect and won’t compile:

```java
// This is wrong!
class MyClass<T extends Comparable<T>> implements MinMax<T> {
```

Once the type parameter has been established, it is simply passed to the interface without further modification.

In general, if a class implements a generic interface, then that class must also be generic, at least to the extent that it takes a type parameter that is passed to the interface. For example, the following attempt to declare MyClass is in error:

```java
class MyClass implements MinMax<T> { // Wrong!
```

Because MyClass does not declare a type parameter, there is no way to pass one to MinMax. In this case, the identifier T is simply unknown, and the compiler reports an error. Of course, if a class implements a specific type of generic interface, such as shown here:

```java
class MyClass implements MinMax<Integer> { // OK
```

then the implementing class does not need to be generic.

The generic interface offers two benefits. First, it can be implemented for different types of data. Second, it allows you to put constraints (that is, bounds) on the types of data for which the interface can be implemented. In the MinMax example, only types that implement the Comparable interface can be passed to T.

Here is the generalized syntax for a generic interface:

```java
interface interface-name<type-param-list> { // …
```

Here, type-param-list is a comma-separated list of type parameters. When a generic interface is implemented, you must specify the type arguments, as shown here:

```java
class class-name<type-param-list>
   implements interface-name<type-arg-list> {
```
Raw Types and Legacy Code

Because support for generics did not exist prior to JDK 5, it was necessary to provide some transition path from old, pre-generics code. Furthermore, this transition path had to enable pre-generics code to remain functional while at the same time being compatible with generics. In other words, pre-generics code had to be able to work with generics, and generic code had to be able to work with pre-generics code.

To handle the transition to generics, Java allows a generic class to be used without any type arguments. This creates a raw type for the class. This raw type is compatible with legacy code, which has no knowledge of generics. The main drawback to using the raw type is that the type safety of generics is lost.

Here is an example that shows a raw type in action:

```java
// Demonstrate a raw type.
class Gen<T> {

    T ob; // declare an object of type T

    // Pass the constructor a reference to
    // an object of type T.
    Gen(T o) {
        ob = o;
    }

    // Return ob.
    T getob() {
        return ob;
    }
}

// Demonstrate raw type.
class RawDemo {
    public static void main(String args[]) {

        // Create a Gen object for Integers.
        Gen<Integer> iOb = new Gen<Integer>(88);
    }
}
```
This program contains several interesting things. First, a raw type of the generic `Gen` class is created by the following declaration:

```java
Gen raw = new Gen(Double.valueOf(98.6));
```

Notice that no type arguments are specified. In essence, this creates a `Gen` object whose type `T` is replaced by `Object`.

A raw type is not type safe. Thus, a variable of a raw type can be assigned a reference to any type of `Gen` object. The reverse is also allowed; a variable of a specific `Gen` type can be assigned a reference to a raw `Gen` object. However, both operations are potentially unsafe because the type checking mechanism of generics is circumvented.

This lack of type safety is illustrated by the commented-out lines at the end of the program. Let’s examine each case. First, consider the following situation:

```java
// int i = (Integer) raw.getob(); // run-time error
```

```java
// This assignment overrides type safety.
strOb = raw; // OK, but potentially wrong
// String str = strOb.getob(); // run-time error
```

```java
// This assignment also overrides type safety.
raw = iOb; // OK, but potentially wrong
// d = (Double) raw.getob(); // run-time error
```
In this statement, the value of `ob` inside `raw` is obtained, and this value is cast to **Integer**. The trouble is that `raw` contains a **Double** value, not an integer value. However, this cannot be detected at compile time because the type of `raw` is unknown. Thus, this statement fails at run time.

The next sequence assigns to a `strOb` (a reference of type **Gen<String>**) a reference to a raw **Gen** object:

```
strOb = raw; // OK, but potentially wrong
//   String str = strOb.getob(); // run-time error
```

The assignment, itself, is syntactically correct, but questionable. Because `strOb` is of type **Gen<String>**, it is assumed to contain a **String**. However, after the assignment, the object referred to by `strOb` contains a **Double**. Thus, at run time, when an attempt is made to assign the contents of `strOb` to `str`, a run-time error results because `strOb` now contains a **Double**. Thus, the assignment of a raw reference to a generic reference bypasses the type-safety mechanism.

The following sequence inverts the preceding case:

```
raw = iOb; // OK, but potentially wrong
//   d = (Double) raw.getob(); // run-time error
```

Here, a generic reference is assigned to a raw reference variable. Although this is syntactically correct, it can lead to problems, as illustrated by the second line. In this case, `raw` now refers to an object that contains an **Integer** object, but the cast assumes that it contains a **Double**. This error cannot be prevented at compile time. Rather, it causes a run-time error.

Because of the potential for danger inherent in raw types, **javac** displays **unchecked warnings** when a raw type is used in a way that might jeopardize type safety. In the preceding program, these lines generate unchecked warnings:

```
Gen raw = new Gen(Double.valueOf(98.6));
strOb = raw; // OK, but potentially wrong
```

In the first line, it is the call to the **Gen** constructor without a type argument that causes the warning. In the second line, it is the assignment of a raw reference to a generic variable that generates the warning.

At first, you might think that this line should also generate an unchecked warning, but it does not:

```
raw = iOb; // OK, but potentially wrong
```
No compiler warning is issued because the assignment does not cause any further loss of type safety than had already occurred when raw was created.

One final point: You should limit the use of raw types to those cases in which you must mix legacy code with newer, generic code. Raw types are simply a transitional feature and not something that should be used for new code.

**Generic Class Hierarchies**

Generic classes can be part of a class hierarchy in just the same way as a non-generic class. Thus, a generic class can act as a superclass or be a subclass. The key difference between generic and non-generic hierarchies is that in a generic hierarchy, any type arguments needed by a generic superclass must be passed up the hierarchy by all subclasses. This is similar to the way that constructor arguments must be passed up a hierarchy.

**Using a Generic Superclass**

Here is a simple example of a hierarchy that uses a generic superclass:

```java
// A simple generic class hierarchy.
class Gen<T> {
  T ob;

  Gen(T o) {
    ob = o;
  }

  // Return ob.
  T getob() {
    return ob;
  }
}

// A subclass of Gen.
class Gen2<T> extends Gen<T> {
  Gen2(T o) {
    super(o);
  }
}
```

In this hierarchy, Gen2 extends the generic class Gen. Notice how Gen2 is declared by the following line:
The type parameter \( T \) is specified by \texttt{Gen2} and is also passed to \texttt{Gen} in the extends clause. This means that whatever type is passed to \texttt{Gen2} will also be passed to \texttt{Gen}. For example, this declaration,

\begin{verbatim}
Gen2<Integer> num = new Gen2<Integer>(100);
\end{verbatim}

passes \texttt{Integer} as the type parameter to \texttt{Gen}. Thus, the \texttt{ob} inside the \texttt{Gen} portion of \texttt{Gen2} will be of type \texttt{Integer}.

Notice also that \texttt{Gen2} does not use the type parameter \( T \) except to support the \texttt{Gen} superclass. Thus, even if a subclass of a generic superclass would otherwise not need to be generic, it still must specify the type parameter(s) required by its generic superclass.

Of course, a subclass is free to add its own type parameters, if needed. For example, here is a variation on the preceding hierarchy in which \texttt{Gen2} adds a type parameter of its own:

\begin{verbatim}
// A subclass can add its own type parameters.
class Gen<T> {
    T ob; // declare an object of type T

    // Pass the constructor a reference to
    // an object of type T.

    // Constructor
    Gen(T object) {
        ob = object;
    }
}
\end{verbatim}
Notice the declaration of this version of `Gen2`, which is shown here:

```java
class Gen2<T, V> extends Gen<T> {
    V ob2;

    Gen2(T o, V o2) {
        super(o);
        ob2 = o2;
    }

    V getob2() {
        return ob2;
    }
}
```

// Create an object of type Gen2.
class HierDemo {
    public static void main(String args[]) {

        // Create a Gen2 object for String and Integer.
        Gen2<String, Integer> x =
            new Gen2<String, Integer>("Value is: ", 99);

        System.out.print(x.getob());
        System.out.println(x.getob2());
    }
}
```

Here, `T` is the type passed to `Gen`, and `V` is the type that is specific to `Gen2`. `V` is used to declare an object called `ob2`, and as a return type for the method `getob2()`. In
main(), a Gen2 object is created in which type parameter T is String, and type parameter V is Integer. The program displays the following, expected, result:

Value is: 99

A Generic Subclass

It is perfectly acceptable for a non-generic class to be the superclass of a generic subclass. For example, consider this program:

```java
// A non-generic class can be the superclass
// of a generic subclass.

// A non-generic class.
class NonGen {
    int num;

    NonGen(int i) {
        num = i;
    }

    int getnum() {
        return num;
    }
}

// A generic subclass.
class Gen<T> extends NonGen {
    T ob; // declare an object of type T
```
The output from the program is shown here:

Hello 47

In the program, notice how Gen inherits NonGen in the following declaration:

class Gen<T> extends NonGen {

Because NonGen is not generic, no type argument is specified. Thus, even though Gen declares the type parameter T, it is not needed by (nor can it be used by) NonGen. Thus, NonGen is inherited by Gen in the normal way. No special conditions apply.

Run-Time Type Comparisons Within a Generic Hierarchy

Recall the run-time type information operator instanceof that was described in Chapter 13. As explained, instanceof determines if an object is an instance of a class. It returns true if an object is of the specified type or can be cast to the specified type. The instanceof operator can be applied to objects of generic classes. The
following class demonstrates some of the type compatibility implications of a
generic hierarchy:

```java
// Use the instanceof operator with a generic class hierarchy.
class Gen<T> {
    T ob;

    Gen(T o) {
        ob = o;
    }

    // Return ob.
    T getob() {
        return ob;
    }
}

// A subclass of Gen.
class Gen2<T> extends Gen<T> {
    Gen2(T o) {
        super(o);
    }
}

// Demonstrate run-time type ID implications of generic
// class hierarchy.
class HierDemo3 {
    public static void main(String args[]) {

        // Create a Gen object for Integers.
        Gen<Integer> iOb = new Gen<Integer>(88);

        // Create a Gen2 object for Integers.
        Gen2<Integer> iOb2 = new Gen2<Integer>(99);
    }
}
```
// Create a Gen2 object for Strings.
Gen2<String> strOb2 = new Gen2<String>("Generics Test");

// See if iOb2 is some form of Gen2.
if(iOb2 instanceof Gen2<?>)
    System.out.println("iOb2 is instance of Gen2");

// See if iOb2 is some form of Gen.
if(iOb2 instanceof Gen<?>)
    System.out.println("iOb2 is instance of Gen");

System.out.println();

// See if strOb2 is a Gen2.
if(strOb2 instanceof Gen2<?>)
    System.out.println("strOb2 is instance of Gen2");

// See if strOb2 is a Gen.
if(strOb2 instanceof Gen<?>)
    System.out.println("strOb2 is instance of Gen");

System.out.println();

// See if iOb is an instance of Gen2, which it is not.
if(iOb instanceof Gen2<?>)
    System.out.println("iOb is instance of Gen2");

// See if iOb is an instance of Gen, which it is.
if(iOb instanceof Gen<?>)
    System.out.println("iOb is instance of Gen");

// The following can't be compiled because
// generic type info does not exist at run time.
//
// if(iOb2 instanceof Gen2<Integer>)
// System.out.println("iOb2 is instance of Gen2<Integer>");
}

The output from the program is shown here:
In this program, Gen2 is a subclass of Gen, which is generic on type parameter T. In main(), three objects are created. The first is iOb, which is an object of type Gen<Integer>. The second is iOb2, which is an instance of Gen2<Integer>. Finally, strOb2 is an object of type Gen2<String>.

Then, the program performs these instanceof tests on the type of iOb2:

```java
// See if iOb2 is some form of Gen2.
if(iOb2 instanceof Gen2<?>)
    System.out.println("iOb2 is instance of Gen2");

// See if iOb2 is some form of Gen.
if(iOb2 instanceof Gen<?>)
    System.out.println("iOb2 is instance of Gen");
```

As the output shows, both succeed. In the first test, iOb2 is checked against Gen2<?>. This test succeeds because it simply confirms that iOb2 is an object of some type of Gen2 object. The use of the wildcard enables instanceof to determine if iOb2 is an object of any type of Gen2. Next, iOb2 is tested against Gen<?>, the superclass type. This is also true because iOb2 is some form of Gen, the superclass. The next few lines in main() show the same sequence (and same results) for strOb2.

Next, iOb, which is an instance of Gen<Integer> (the superclass), is tested by these lines:

```java
// See if iOb is an instance of Gen2, which it is not.
if(iOb instanceof Gen2<?>)
    System.out.println("iOb is instance of Gen2");

// See if iOb is an instance of Gen, which it is.
if(iOb instanceof Gen<?>)
    System.out.println("iOb is instance of Gen");
```

The first if fails because iOb is not some type of Gen2 object. The second test succeeds because iOb is some type of Gen object.

Now, look closely at these commented-out lines:
As the comments indicate, these lines can’t be compiled because they attempt to compare `iOb2` with a specific type of `Gen2`, in this case, `Gen2<Integer>`. Remember, there is no generic type information available at run time. Therefore, there is no way for `instanceof` to know if `iOb2` is an instance of `Gen2<Integer>` or not.

**Casting**

You can cast one instance of a generic class into another only if the two are otherwise compatible and their type arguments are the same. For example, assuming the foregoing program, this cast is legal:

```
(Gen<Integer>) iOb2 // legal
```

because `iOb2` includes an instance of `Gen<Integer>`. But, this cast:

```
(Gen<Long>) iOb2 // illegal
```

is not legal because `iOb2` is not an instance of `Gen<Long>`.

**Overriding Methods in a Generic Class**

A method in a generic class can be overridden just like any other method. For example, consider this program in which the method `getob()` is overridden:
// Overriding a generic method in a generic class.
class Gen<T> {
    T ob; // declare an object of type T

    // Pass the constructor a reference to
    // an object of type T.
    Gen(T o) {
        ob = o;
    }

    // Return ob.
    T getob() {
        System.out.print("Gen's getob(): ");
        return ob;
    }
}

// A subclass of Gen that overrides getob().
class Gen2<T> extends Gen<T> {

    Gen2(T o) {
        super(o);
    }
}
// Override getob().
T getob() {
    System.out.println("Gen2's getob(): ");
    return ob;
}

// Demonstrate generic method override.
class OverrideDemo {
    public static void main(String args[]) {

        // Create a Gen object for Integers.
        Gen<Integer> iOb = new Gen<Integer>(88);

        // Create a Gen2 object for Integers.
        Gen2<Integer> iOb2 = new Gen2<Integer>(99);

        // Create a Gen2 object for Strings.
        Gen2<String> strOb2 = new Gen2<String> ("Generics Test");

        System.out.println(iOb.getob());
        System.out.println(iOb2.getob());
        System.out.println(strOb2.getob());
    }
}

The output is shown here:

    Gen's getob(): 88
    Gen2's getob(): 99
    Gen2's getob(): Generics Test

As the output confirms, the overridden version of getob() is called for objects of type Gen2, but the superclass version is called for objects of type Gen.

**Type Inference with Generics**

Beginning with JDK 7, it is possible to shorten the syntax used to create an instance of a generic type. To begin, consider the following generic class:
Prior to JDK 7, to create an instance of `MyClass`, you would have needed to use a statement similar to the following:

```java
MyClass<T o1, V o2> mcOb =
    new MyClass<T, V>(98, "A String");
```

Here, the type arguments (which are `Integer` and `String`) are specified twice: first, when `mcOb` is declared, and second, when a `MyClass` instance is created via `new`. Since generics were introduced by JDK 5, this is the form required by all versions of Java prior to JDK 7. Although there is nothing wrong, per se, with this form, it is a bit more verbose than it needs to be. In the `new` clause, the type of the type arguments can be readily inferred from the type of `mcOb`; therefore, there is really no reason that they need to be specified a second time. To address this situation, JDK 7 added a syntactic element that lets you avoid the second specification.

Today the preceding declaration can be rewritten as shown here:

```java
MyClass<Integer, String> mcOb =
    new MyClass<>(98, "A String");
```

Notice that the instance creation portion simply uses `<>`, which is an empty type argument list. This is referred to as the diamond operator. It tells the compiler to infer the type arguments needed by the constructor in the `new` expression. The principal advantage of this type-inference syntax is that it shortens what are sometimes quite long declaration statements.

The preceding can be generalized. When type inference is used, the declaration syntax for a generic reference and instance creation has this general form:

```
class-name<type-arg-list > var-name = new class-name <> (cons-arg-list);
```

Here, the type argument list of the constructor in the `new` clause is empty.

Type inference can also be applied to parameter passing. For example, if the following method is added to `MyClass`,

```java
class MyClass<T, V> {
    T ob1;
    V ob2;

    MyClass(T o1, V o2) {
        ob1 = o1;
        ob2 = o2;
    }
    // ...
}
```
then the following call is legal:

```java
if(mcOb.isSame(new MyClass<>\(1, "test")\)) System.out.println("Same");
```

In this case, the type arguments for the argument passed to `isSame()` can be inferred from the parameter’s type.

Most of the examples in this book will continue to use the full syntax when declaring instances of generic classes. This way, the examples will work with any Java compiler that supports generics. Using the full-length syntax also makes it very clear precisely what is being created, which is important in example code shown in a book. However, in your own code, the use of the type-inference syntax will streamline your declarations.

## Erasure

Usually, it is not necessary to know the details about how the Java compiler transforms your source code into object code. However, in the case of generics, some general understanding of the process is important because it explains why the generic features work as they do—and why their behavior is sometimes a bit surprising. For this reason, a brief discussion of how generics are implemented in Java is in order.

An important constraint that governed the way that generics were added to Java was the need for compatibility with previous versions of Java. Simply put, generic code had to be compatible with preexisting, non-generic code. Thus, any changes to the syntax of the Java language, or to the JVM, had to avoid breaking older code. The way Java implements generics while satisfying this constraint is through the use of **erasure**.

In general, here is how erasure works. When your Java code is compiled, all generic type information is removed (erased). This means replacing type parameters with their bound type, which is **Object** if no explicit bound is specified, and then applying the appropriate casts (as determined by the type arguments) to maintain type compatibility with the types specified by the type arguments. The compiler also enforces this type compatibility. This approach to generics means that no type parameters exist at run time. They are simply a source-code mechanism.

## Bridge Methods
Occasionally, the compiler will need to add a *bridge method* to a class to handle situations in which the type erasure of an overriding method in a subclass does not produce the same erasure as the method in the superclass. In this case, a method is generated that uses the type erasure of the superclass, and this method calls the method that has the type erasure specified by the subclass. Of course, bridge methods only occur at the bytecode level, are not seen by you, and are not available for your use.

Although bridge methods are not something that you will normally need to be concerned with, it is still instructive to see a situation in which one is generated. Consider the following program:
In the program, the subclass `Gen2` extends `Gen`, but does so using a `String`-specific version of `Gen`, as its declaration shows:
Furthermore, inside `Gen2`, `getob()` is overridden with `String` specified as the return type:

```java
// A String-specific override of getob().
String getob() {
    System.out.print("You called String getob(): ");
    return ob;
}
```

All of this is perfectly acceptable. The only trouble is that because of type erasure, the expected form of `getob()` will be

```java
Object getob() { // ...
```

To handle this problem, the compiler generates a bridge method with the preceding signature that calls the `String` version. Thus, if you examine the class file for `Gen2` by using `javap`, you will see the following methods:

```java
class Gen2 extends Gen<java.lang.String> {
    Gen2(java.lang.String);
    java.lang.String getob();
    java.lang.Object getob(); // bridge method
}
```

As you can see, the bridge method has been included. (The comment was added by the author and not by `javap`, and the precise output you see may vary based on the version of Java that you are using.)

There is one last point to make about this example. Notice that the only difference between the two `getob()` methods is their return type. Normally, this would cause an error, but because this does not occur in your source code, it does not cause a problem and is handled correctly by the JVM.

### Ambiguity Errors

The inclusion of generics gives rise to another type of error that you must guard against: *ambiguity*. Ambiguity errors occur when erasure causes two seemingly distinct generic declarations to resolve to the same erased type, causing a conflict. Here is an example that involves method overloading:
Notice that MyGenClass declares two generic types: T and V. Inside MyGenClass, an attempt is made to overload set() based on parameters of type T and V. This looks reasonable because T and V appear to be different types. However, there are two ambiguity problems here.

First, as MyGenClass is written, there is no requirement that T and V actually be different types. For example, it is perfectly correct (in principle) to construct a MyGenClass object as shown here:

MyGenClass<String, String> obj = new MyGenClass<String, String>();

In this case, both T and V will be replaced by String. This makes both versions of set() identical, which is, of course, an error.

The second and more fundamental problem is that the type erasure of set() reduces both versions to the following:

void set(Object o) { // ...

Thus, the overloading of set() as attempted in MyGenClass is inherently ambiguous.

Ambiguity errors can be tricky to fix. For example, if you know that V will always be some type of Number, you might try to fix MyGenClass by rewriting its declaration as shown here:

class MyGenClass<T, V extends Number> { // almost OK!
This change causes **MyGenClass** to compile, and you can even instantiate objects like the one shown here:

```java
MyGenClass<String, Number> x = new MyGenClass<String, Number>();
```

This works because Java can accurately determine which method to call. However, ambiguity returns when you try this line:

```java
MyGenClass<Number, Number> x = new MyGenClass<Number, Number>();
```

In this case, since both **T** and **V** are **Number**, which version of **set()** is to be called? The call to **set()** is now ambiguous.

Frankly, in the preceding example, it would be much better to use two separate method names, rather than trying to overload **set()**. Often, the solution to ambiguity involves the restructuring of the code, because ambiguity frequently means that you have a conceptual error in your design.

**Some Generic Restrictions**

There are a few restrictions that you need to keep in mind when using generics. They involve creating objects of a type parameter, static members, exceptions, and arrays. Each is examined here.

**Type Parameters Can’t Be Instantiated**

It is not possible to create an instance of a type parameter. For example, consider this class:

```java
// Can't create an instance of T.
class Gen<T> {
    T ob;

    Gen() {
        ob = new T(); // Illegal!!!
    }
}
```

Here, it is illegal to attempt to create an instance of **T**. The reason should be easy to understand: the compiler does not know what type of object to create. **T** is simply a placeholder.

**Restrictions on Static Members**
No `static` member can use a type parameter declared by the enclosing class. For example, both of the `static` members of this class are illegal:

```java
class Wrong<T> {
    // Wrong, no static variables of type T.
    static T ob;

    // Wrong, no static method can use T.
    static T getob() {
        return ob;
    }
}
```

Although you can’t declare `static` members that use a type parameter declared by the enclosing class, you can declare `static` generic methods, which define their own type parameters, as was done earlier in this chapter.

## Generic Array Restrictions

There are two important generics restrictions that apply to arrays. First, you cannot instantiate an array whose element type is a type parameter. Second, you cannot create an array of type-specific generic references. The following short program shows both situations:

```java
// Generics and arrays.
class Gen<T extends Number> {
    T ob;
```
As the program shows, it’s valid to declare a reference to an array of type $T$, as this line does:

$$T \ text{vals[]} \; // \text{OK}$$

But, you cannot instantiate an array of $T$, as this commented-out line attempts:

$$// \text{vals} = \text{new} \ T[10]; \; // \text{can't create an array of } T$$

The reason you can’t create an array of $T$ is that there is no way for the compiler to know what type of array to actually create.

However, you can pass a reference to a type-compatible array to $\text{Gen}()$ when an object is created and assign that reference to $\text{vals}$, as the program does in this line:

$$\text{vals} = \text{nums}; \; // \text{OK to assign reference to existent array}$$

This works because the array passed to $\text{Gen}$ has a known type, which will be the
same type as `T` at the time of object creation.

Inside `main()`, notice that you can’t declare an array of references to a specific generic type. That is, this line

```java
// Gen<Integer> gens[] = new Gen<Integer>[10]; // Wrong!
```

won’t compile.

You can create an array of references to a generic type if you use a wildcard, however, as shown here:

```java
Gen<?> gens[] = new Gen<?>[10]; // OK
```

This approach is better than using an array of raw types, because at least some type checking will still be enforced.

**Generic Exception Restriction**

A generic class cannot extend `Throwable`. This means that you cannot create generic exception classes.
CHAPTER
During Java’s ongoing development and evolution, many features have been added since its original 1.0 release. However, two stand out because they have profoundly reshaped the language, fundamentally changing the way that code is written. The first was the addition of generics, added by JDK 5. (See Chapter 14.) The second is the lambda expression, which is the subject of this chapter.

Added by JDK 8, lambda expressions (and their related features) significantly enhanced Java because of two primary reasons. First, they added new syntax elements that increased the expressive power of the language. In the process, they streamlined the way that certain common constructs are implemented. Second, the addition of lambda expressions resulted in new capabilities being incorporated into the API library. Among these new capabilities are the ability to more easily take advantage of the parallel processing capabilities of multi-core environments, especially as it relates to the handling of for-each style operations, and the new stream API, which supports pipeline operations on data. The addition of lambda expressions also provided the catalyst for other new Java features, including the default method (described in Chapter 9), which lets you define default behavior for an interface method, and the method reference (described here), which lets you refer to a method without executing it.

In the final analysis, in much the same way that generics reshaped Java several years ago, lambda expressions continue to reshape Java today. Simply put, lambda expressions will impact virtually all Java programmers. They truly are that important.

**Introducing Lambda Expressions**

Key to understanding Java’s implementation of lambda expressions are two constructs. The first is the lambda expression, itself. The second is the functional interface. Let’s begin with a simple definition of each.

A lambda expression is, essentially, an anonymous (that is, unnamed) method. However, this method is not executed on its own. Instead, it is used to implement a method defined by a functional interface. Thus, a lambda expression results in a form of anonymous class. Lambda expressions are also commonly referred to as closures.
A functional interface is an interface that contains one and only one abstract method. Normally, this method specifies the intended purpose of the interface. Thus, a functional interface typically represents a single action. For example, the standard interface `Runnable` is a functional interface because it defines only one method: `run()`. Therefore, `run()` defines the action of `Runnable`. Furthermore, a functional interface defines the target type of a lambda expression. Here is a key point: a lambda expression can be used only in a context in which its target type is specified. One other thing: a functional interface is sometimes referred to as a `SAM type`, where SAM stands for Single Abstract Method.

**NOTE** A functional interface may specify any public method defined by `Object`, such as `equals()`, without affecting its “functional interface” status. The public `Object` methods are considered implicit members of a functional interface because they are automatically implemented by an instance of a functional interface.

Let’s now look more closely at both lambda expressions and functional interfaces.

**Lambda Expression Fundamentals**

The lambda expression introduced a new syntax element and operator into the Java language. The new operator, sometimes referred to as the lambda operator or the arrow operator, is `->`. It divides a lambda expression into two parts. The left side specifies any parameters required by the lambda expression. (If no parameters are needed, an empty parameter list is used.) On the right side is the lambda body, which specifies the actions of the lambda expression. The `->` can be verbalized as “becomes” or “goes to.”

Java defines two types of lambda bodies. One consists of a single expression, and the other type consists of a block of code. We will begin with lambdas that define a single expression. Lambdas with block bodies are discussed later in this chapter.

At this point, it will be helpful to look a few examples of lambda expressions before continuing. Let’s begin with what is probably the simplest type of lambda expression you can write. It evaluates to a constant value and is shown here:

```
() -> 123.45
```

This lambda expression takes no parameters, thus the parameter list is empty. It returns the constant value 123.45. Therefore, it is similar to the following method:

```java
double myMeth() { return 123.45; }
```
Of course, the method defined by a lambda expression does not have a name. A slightly more interesting lambda expression is shown here:

```
() -> Math.random() * 100
```

This lambda expression obtains a pseudo-random value from `Math.random()`, multiplies it by 100, and returns the result. It, too, does not require a parameter.

When a lambda expression requires a parameter, it is specified in the parameter list on the left side of the lambda operator. Here is a simple example:

```
(n) -> (n % 2)==0
```

This lambda expression returns `true` if the value of parameter `n` is even. Although it is possible to explicitly specify the type of a parameter, such as `n` in this case, often you won’t need to do so because in many cases its type can be inferred. Like a named method, a lambda expression can specify as many parameters as needed.

### Functional Interfaces

As stated, a functional interface is an interface that specifies only one abstract method. If you have been programming in Java for some time, you might at first think that all interface methods are implicitly abstract. Although this was true prior to JDK 8, the situation has changed. As explained in Chapter 9, beginning with JDK 8, it is possible to specify a default implementation for a method declared in an interface. Private and static interface methods also supply an implementation. As a result, today, an interface method is abstract only if it does not specify an implementation. Because non-default non-static, non-private interface methods are implicitly abstract, there is no need to use the `abstract` modifier (although you can specify it, if you like).

Here is an example of a functional interface:

```java
interface MyNumber {
    double getValue();
}
```

In this case, the method `getValue()` is implicitly abstract, and it is the only method defined by `MyNumber`. Thus, `MyNumber` is a functional interface, and its function is defined by `getValue()`.

As mentioned earlier, a lambda expression is not executed on its own. Rather, it forms the implementation of the abstract method defined by the functional interface that specifies its target type. As a result, a lambda expression can be specified only in a context in which a target type is defined. One of these contexts is created when a
lambda expression is assigned to a functional interface reference. Other target type contexts include variable initialization, return statements, and method arguments, to name a few.

Let’s work through an example that shows how a lambda expression can be used in an assignment context. First, a reference to the functional interface `MyNumber` is declared:

```java
// Create a reference to a MyNumber instance.
MyNumber myNum;
```

Next, a lambda expression is assigned to that interface reference:

```java
// Use a lambda in an assignment context.
myNum = () -> 123.45;
```

When a lambda expression occurs in a target type context, an instance of a class is automatically created that implements the functional interface, with the lambda expression defining the behavior of the abstract method declared by the functional interface. When that method is called through the target, the lambda expression is executed. Thus, a lambda expression gives us a way to transform a code segment into an object.

In the preceding example, the lambda expression becomes the implementation for the `getValue()` method. As a result, the following displays the value 123.45:

```java
// Call getValue(), which is implemented by the previously assigned // lambda expression.
System.out.println(myNum.getValue());
```

Because the lambda expression assigned to `myNum` returns the value 123.45, that is the value obtained when `getValue()` is called.

In order for a lambda expression to be used in a target type context, the type of the abstract method and the type of the lambda expression must be compatible. For example, if the abstract method specifies two `int` parameters, then the lambda must specify two parameters whose type either is explicitly `int` or can be implicitly inferred as `int` by the context. In general, the type and number of the lambda expression’s parameters must be compatible with the method’s parameters; the return types must be compatible; and any exceptions thrown by the lambda expression must be acceptable to the method.

**Some Lambda Expression Examples**

With the preceding discussion in mind, let’s look at some simple examples that
illustrate the basic lambda expression concepts. The first example puts together the pieces shown in the foregoing section.

    // Demonstrate a simple lambda expression.
    // A functional interface.
    interface MyNumber {
        double getValue();
    }

    class LambdaDemo {
        public static void main(String args[]) {
            MyNumber myNum; // declare an interface reference

            // Here, the lambda expression is simply a constant expression.
            // When it is assigned to myNum, a class instance is
            // constructed in which the lambda expression implements
            // the getValue() method in MyNumber.
            myNum = () -> 123.45;

            // Call getValue(), which is provided by the previously assigned
            // lambda expression.
            System.out.println("A fixed value: " + myNum.getValue());

            // Here, a more complex expression is used.
            myNum = () -> Math.random() * 100;

            // These call the lambda expression in the previous line.
            System.out.println("A random value: " + myNum.getValue());
            System.out.println("Another random value: " + myNum.getValue());

            // A lambda expression must be compatible with the method
            // defined by the functional interface. Therefore, this won't work:
            // myNum = () -> "123.03"; // Error!
        }
    }

Sample output from the program is shown here:

A fixed value: 123.45
A random value: 88.90663650412304
Another random value: 53.00582701784129
As mentioned, the lambda expression must be compatible with the abstract method that it is intended to implement. For this reason, the commented-out line at the end of the preceding program is illegal because a value of type String is not compatible with double, which is the return type required by getValue().

The next example shows the use of a parameter with a lambda expression:

```java
// Demonstrate a lambda expression that takes a parameter.

// Another functional interface.
interface NumericTest {
    boolean test(int n);
}

class LambdaDemo2 {
    public static void main(String args[])
    {
        // A lambda expression that tests if a number is even.
        NumericTest isEven = (n) -> (n % 2)==0;

        if(isEven.test(10)) System.out.println("10 is even");
        if(!isEven.test(9)) System.out.println("9 is not even");

        // Now, use a lambda expression that tests if a number
        // is non-negative.
        NumericTest isNonNeg = (n) -> n >= 0;

        if(isNonNeg.test(1)) System.out.println("1 is non-negative");
        if(!isNonNeg.test(-1)) System.out.println("-1 is negative");
    }
}
```

The output from this program is shown here:

```
10 is even
9 is not even
1 is non-negative
-1 is negative
```

This program demonstrates a key fact about lambda expressions that warrants close examination. Pay special attention to the lambda expression that performs the test for evenness. It is shown again here:

`(n) -> (n % 2)==0`
Notice that the type of n is not specified. Rather, its type is inferred from the context. In this case, its type is inferred from the parameter type of test( ) as defined by the NumericTest interface, which is int. It is also possible to explicitly specify the type of a parameter in a lambda expression. For example, this is also a valid way to write the preceding:

\[(\text{int } n) \rightarrow (n \% 2)==0\]

Here, n is explicitly specified as int. Usually it is not necessary to explicitly specify the type, but you can in those situations that require it.

This program demonstrates another important point about lambda expressions: A functional interface reference can be used to execute any lambda expression that is compatible with it. Notice that the program defines two different lambda expressions that are compatible with the test( ) method of the functional interface NumericTest. The first, called isEven, determines if a value is even. The second, called isNonNeg, checks if a value is non-negative. In each case, the value of the parameter n is tested. Because each lambda expression is compatible with test( ), each can be executed through a NumericTest reference.

One other point before moving on. When a lambda expression has only one parameter, it is not necessary to surround the parameter name with parentheses when it is specified on the left side of the lambda operator. For example, this is also a valid way to write the lambda expression used in the program:

\[n \rightarrow (n \% 2)==0\]

For consistency, this book will surround all lambda expression parameter lists with parentheses, even those containing only one parameter. Of course, you are free to adopt a different style.

The next program demonstrates a lambda expression that takes two parameters. In this case, the lambda expression tests if one number is a factor of another.
interface NumericTest2 {
    boolean test(int n, int d);
}

class LambdaDemo3 {
    public static void main(String args[]) {
        // This lambda expression determines if one number is
        // a factor of another.
        NumericTest2 isFactor = (n, d) -> (n % d) == 0;

        if(isFactor.test(10, 2))
            System.out.println("2 is a factor of 10");

        if(!isFactor.test(10, 3))
            System.out.println("3 is not a factor of 10");
    }
}

The output is shown here:

2 is a factor of 10
3 is not a factor of 10

In this program, the functional interface NumericTest2 defines the test() method:

boolean test(int n, int d);

In this version, test() specifies two parameters. Thus, for a lambda expression to be compatible with test(), the lambda expression must also specify two parameters. Notice how they are specified:

(n, d) -> (n % d) == 0

The two parameters, n and d, are specified in the parameter list, separated by commas. This example can be generalized. Whenever more than one parameter is required, the parameters are specified, separated by commas, in a parenthesized list on the left side of the lambda operator.

Here is an important point about multiple parameters in a lambda expression: If you need to explicitly declare the type of a parameter, then all of the parameters must have declared types. For example, this is legal:
(int n, int d) -> (n % d) == 0

But this is not:
(int n, d) -> (n % d) == 0

**Block Lambda Expressions**

The body of the lambdas shown in the preceding examples consist of a single expression. These types of lambda bodies are referred to as *expression bodies*, and lambdas that have expression bodies are sometimes called *expression lambdas*. In an expression body, the code on the right side of the lambda operator must consist of a single expression. While expression lambdas are quite useful, sometimes the situation will require more than a single expression. To handle such cases, Java supports a second type of lambda expression in which the code on the right side of the lambda operator consists of a block of code that can contain more than one statement. This type of lambda body is called a *block body*. Lambdas that have block bodies are sometimes referred to as *block lambdas*.

A block lambda expands the types of operations that can be handled within a lambda expression because it allows the body of the lambda to contain multiple statements. For example, in a block lambda you can declare variables, use loops, specify if and switch statements, create nested blocks, and so on. A block lambda is easy to create. Simply enclose the body within braces as you would any other block of statements.

Aside from allowing multiple statements, block lambdas are used much like the expression lambdas just discussed. One key difference, however, is that you must explicitly use a return statement to return a value. This is necessary because a block lambda body does not represent a single expression.

Here is an example that uses a block lambda to compute and return the factorial of an int value:
// A block lambda that computes the factorial of an int value.

interface NumericFunc {
    int func(int n);
}

class BlockLambdaDemo {
    public static void main(String args[])
    {
        // This block lambda computes the factorial of an int value.
        NumericFunc factorial = (n) -> {
            int result = 1;
            for(int i=1; i <= n; i++)
                result = i * result;
            return result;
        };
        System.out.println("The factorial of 3 is " + factorial.func(3));
        System.out.println("The factorial of 5 is " + factorial.func(5));
    }
}

The output is shown here:
The factorial of 3 is 6  
The factorial of 5 is 120

In the program, notice that the block lambda declares a variable called \texttt{result}, uses a \texttt{for} loop, and has a \texttt{return} statement. These are legal inside a block lambda body. In essence, the block body of a lambda is similar to a method body. One other point. When a \texttt{return} statement occurs within a lambda expression, it simply causes a return from the lambda. It does not cause an enclosing method to return.

Another example of a block lambda is shown in the following program. It reverses the characters in a string.
// A block lambda that reverses the characters in a string.

interface StringFunc {
    String func(String n);
}

class BlockLambdaDemo2 {
    public static void main(String args[])
    {

        // This block lambda reverses the characters in a string.
        StringFunc reverse = (str) -> {
            String result = "";
            int i;

            for (i = str.length() - 1; i >= 0; i--)
                result += str.charAt(i);

            return result;
        };

        System.out.println("Lambda reversed is " +
                           reverse.func("Lambda"));
        System.out.println("Expression reversed is " +
                           reverse.func("Expression"));
    }
}

The output is shown here:

Lambda reversed is adbmAL
Expression reversed is noisserpxE

In this example, the functional interface StringFunc declares the func() method. This method takes a parameter of type String and has a return type of String. Thus, in the reverse lambda expression, the type of str is inferred to be String. Notice that the charAt() method is called on str. This is legal because of the inference that str is of type String.

Generic Functional Interfaces

A lambda expression, itself, cannot specify type parameters. Thus, a lambda expression cannot be generic. (Of course, because of type inference, all lambda
expressions exhibit some “generic-like” qualities.) However, the functional interface associated with a lambda expression can be generic. In this case, the target type of the lambda expression is determined, in part, by the type argument or arguments specified when a functional interface reference is declared.

To understand the value of generic functional interfaces, consider this. The two examples in the previous section used two different functional interfaces, one called `NumericFunc` and the other called `StringFunc`. However, both defined a method called `func()` that took one parameter and returned a result. In the first case, the type of the parameter and return type was `int`. In the second case, the parameter and return type was `String`. Thus, the only difference between the two methods was the type of data they required. Instead of having two functional interfaces whose methods differ only in their data types, it is possible to declare one generic interface that can be used to handle both circumstances. The following program shows this approach:
// Use a generic functional interface with lambda expressions.

// A generic functional interface.
interface SomeFunc<T> {
    T func(T t);
}

class GenericFunctionalInterfaceDemo {
    public static void main(String args[]) {

        // Use a String-based version of SomeFunc.
        SomeFunc<String> reverse = (str) -> {
            String result = "";
            int i;

            for(i = str.length()-1; i >= 0; i--)
                result += str.charAt(i);

            return result;
        };

        System.out.println("Lambda reversed is " + reverse.func("Lambda"));
        System.out.println("Expression reversed is " + reverse.func("Expression"));

        // Now, use an Integer-based version of SomeFunc.
        SomeFunc<Integer> factorial = (n) -> {
            int result = 1;

            for(int i=1; i <= n; i++)
                result = i * result;

            return result;
        };

        System.out.println("The factorial of 3 is " + factorial.func(3));
        System.out.println("The factorial of 5 is " + factorial.func(5));
    }
}

The output is shown here:
Lambda reversed is adbmaL
Expression reversed is noisserpxE
The factorial of 3 is 6
The factorial of 5 is 120

In the program, the generic functional interface `SomeFunc` is declared as shown here:

```java
interface SomeFunc<T> {
    T func(T t);
}
```

Here, `T` specifies both the return type and the parameter type of `func()`. This means that it is compatible with any lambda expression that takes one parameter and returns a value of the same type.

The `SomeFunc` interface is used to provide a reference to two different types of lambdas. The first uses type `String`. The second uses type `Integer`. Thus, the same functional interface can be used to refer to the `reverse` lambda and the `factorial` lambda. Only the type argument passed to `SomeFunc` differs.

## Passing Lambda Expressions as Arguments

As explained earlier, a lambda expression can be used in any context that provides a target type. One of these is when a lambda expression is passed as an argument. In fact, passing a lambda expression as an argument is a common use of lambdas. Moreover, it is a very powerful use because it gives you a way to pass executable code as an argument to a method. This greatly enhances the expressive power of Java.

To pass a lambda expression as an argument, the type of the parameter receiving the lambda expression argument must be of a functional interface type compatible with the lambda. Although using a lambda expression as an argument is straightforward, it is still helpful to see it in action. The following program demonstrates the process:
// Use lambda expressions as an argument to a method.

interface StringFunc {
    String func(String n);
}

class LambdasAsArgumentsDemo {
    // This method has a functional interface as the type of
    // its first parameter. Thus, it can be passed a reference to
    // any instance of that interface, including the instance created
    // by a lambda expression.
    // The second parameter specifies the string to operate on.
    static String stringOp(StringFunc sf, String s) {
        return sf.func(s);
    }

    public static void main(String args[]) {
        String inStr = "Lambdas add power to Java";
        String outStr;

        System.out.println("Here is input string: " + inStr);

        // Here, a simple expression lambda that uppercases a string
        // is passed to stringOp().
        outStr = stringOp((str) -> str.toUpperCase(), inStr);
        System.out.println("The string in uppercase: " + outStr);

        // This passes a block lambda that removes spaces.
        outStr = stringOp((str) -> {
            String result = "";
            int i;

            for(i = 0; i < str.length(); i++)
                if(str.charAt(i) != ' ')
                    result += str.charAt(i);

            return result;
        }, inStr);

        System.out.println("The string with spaces removed: " + outStr);

        // Of course, it is also possible to pass a StringFunc instance
        // created by an earlier lambda expression. For example,
        // after this declaration executes, reverse refers to an
        // instance of StringFunc.
        StringFunc reverse = (str) -> {
            String result = "";
            int i;

            for(i = str.length()-1; i >= 0; i--)
                result += str.charAt(i);

            return result;
        };

        // Now, reverse can be passed as the first parameter to stringOp()
        // since it refers to a StringFunc object.
        System.out.println("The string reversed: " +
            stringOp(reverse, inStr));
    }
}
In the program, first notice the `stringOp()` method. It has two parameters. The first is of type `StringFunc`, which is a functional interface. Thus, this parameter can receive a reference to any instance of `StringFunc`, including one created by a lambda expression. The second argument of `stringOp()` is of type `String`, and this is the string operated on.

Next, notice the first call to `stringOp()`, shown again here:

```java
outStr = stringOp((str) -> str.toUpperCase(), inStr);
```

Here, a simple expression lambda is passed as an argument. When this occurs, an instance of the functional interface `StringFunc` is created and a reference to that object is passed to the first parameter of `stringOp()`. Thus, the lambda code, embedded in a class instance, is passed to the method. The target type context is determined by the type of parameter. Because the lambda expression is compatible with that type, the call is valid. Embedding simple lambdas, such as the one just shown, inside a method call is often a convenient technique—especially when the lambda expression is intended for a single use.

Next, the program passes a block lambda to `stringOp()`. This lambda removes spaces from a string. It is shown again here:

```java
outStr = stringOp((str) -> {
    String result = "";
    int i;

    for(i = 0; i < str.length(); i++)
        if(str.charAt(i) != ' ')
            result += str.charAt(i);

    return result;
}, inStr);
```

Although this uses a block lambda, the process of passing the lambda expression is the same as just described for the simple expression lambda. In this case, however, some programmers will find the syntax a bit awkward.
When a block lambda seems overly long to embed in a method call, it is an easy matter to assign that lambda to a functional interface variable, as the previous examples have done. Then, you can simply pass that reference to the method. This technique is shown at the end of the program. There, a block lambda is defined that reverses a string. This lambda is assigned to `reverse`, which is a reference to a `StringFunc` instance. Thus, `reverse` can be used as an argument to the first parameter of `stringOp()`. The program then calls `stringOp()`, passing in `reverse` and the string on which to operate. Because the instance obtained by the evaluation of each lambda expression is an implementation of `StringFunc`, each can be used as the first parameter to `stringOp()`.

One last point: In addition to variable initialization, assignment, and argument passing, the following also constitute target type contexts: casts, the `?` operator, array initializers, `return` statements, and lambda expressions, themselves.

**Lambda Expressions and Exceptions**

A lambda expression can throw an exception. However, if it throws a checked exception, then that exception must be compatible with the exception(s) listed in the `throws` clause of the abstract method in the functional interface. Here is an example that illustrates this fact. It computes the average of an array of `double` values. If a zero-length array is passed, however, it throws the custom exception `EmptyArrayException`. As the example shows, this exception is listed in the `throws` clause of `func()` declared inside the `DoubleNumericArrayFunc` functional interface.
The first call to `average.func()` returns the value 2.5. The second call, which passes a zero-length array, causes an `EmptyArrayException` to be thrown. Remember, the inclusion of the `throws` clause in `func()` is necessary. Without it, the program will not compile because the lambda expression will no longer be compatible with `func()`.
This example demonstrates another important point about lambda expressions. Notice that the parameter specified by `func()` in the functional interface `DoubleNumericArrayFunc` is an array. However, the parameter to the lambda expression is simply `n`, rather than `n[]`. Remember, the type of a lambda expression parameter will be inferred from the target context. In this case, the target context is `double[]`, thus the type of `n` will be `double[]`. It is not necessary (or legal) to specify it as `n[]`. It would be legal to explicitly declare it as `double[] n`, but doing so gains nothing in this case.

**Lambda Expressions and Variable Capture**

Variables defined by the enclosing scope of a lambda expression are accessible within the lambda expression. For example, a lambda expression can use an instance or `static` variable defined by its enclosing class. A lambda expression also has access to `this` (both explicitly and implicitly), which refers to the invoking instance of the lambda expression’s enclosing class. Thus, a lambda expression can obtain or set the value of an instance or `static` variable and call a method defined by its enclosing class.

However, when a lambda expression uses a local variable from its enclosing scope, a special situation is created that is referred to as a `variable capture`. In this case, a lambda expression may only use local variables that are `effectively final`. An effectively final variable is one whose value does not change after it is first assigned. There is no need to explicitly declare such a variable as `final`, although doing so would not be an error. (The `this` parameter of an enclosing scope is automatically effectively final, and lambda expressions do not have a `this` of their own.)

It is important to understand that a local variable of the enclosing scope cannot be modified by the lambda expression. Doing so would remove its effectively final status, thus rendering it illegal for capture.

The following program illustrates the difference between effectively final and mutable local variables:
As the comments indicate, `num` is effectively final and can, therefore, be used inside `myLambda`. However, if `num` were to be modified, either inside the lambda or outside of it, `num` would lose its effectively final status. This would cause an error, and the program would not compile.

It is important to emphasize that a lambda expression can use and modify an instance variable from its invoking class. It just can’t use a local variable of its enclosing scope unless that variable is effectively final.

### Method References

There is an important feature related to lambda expressions called the *method reference*. A method reference provides a way to refer to a method without executing it. It relates to lambda expressions because it, too, requires a target type context that consists of a compatible functional interface. When evaluated, a method reference
also creates an instance of the functional interface.

There are different types of method references. We will begin with method references to **static** methods.

**Method References to static Methods**

To create a **static** method reference, use this general syntax:

```
ClassName::methodName
```

Notice that the class name is separated from the method name by a double colon. The `::` is a separator that was added to Java by JDK 8 expressly for this purpose. This method reference can be used anywhere in which it is compatible with its target type.

The following program demonstrates a **static** method reference:
// Demonstrate a method reference for a static method.

// A functional interface for string operations.
interface StringFunc {
    String func(String n);
}

// This class defines a static method called strReverse().
class MyStringOps {
    // A static method that reverses a string.
    static String strReverse(String str) {
        String result = "";
        int i;

        for(i = str.length()-1; i >= 0; i--)
            result += str.charAt(i);

        return result;
    }
}

class MethodRefDemo {

    // This method has a functional interface as the type of
    // its first parameter. Thus, it can be passed any instance
    // of that interface, including a method reference.
    static String stringOp(StringFunc sf, String s) {
        return sf.func(s);
    }

    public static void main(String args[]) {
        String inStr = "Lambdas add power to Java";
        String outStr;

        // Here, a method reference to strReverse is passed to stringOp().
        outStr = stringOp(MyStringOps::strReverse, inStr);

        System.out.println("Original string: " + inStr);
        System.out.println("String reversed: " + outStr);
    }
}
The output is shown here:

Original string: Lambdas add power to Java
String reversed: avaJ ot rewop dda sadbmaL

In the program, pay special attention to this line:

```
outStr = stringOp(MyStringOps::strReverse, inStr);
```

Here, a reference to the static method `strReverse()`, declared inside `MyStringOps`, is passed as the first argument to `stringOp()`. This works because `strReverse` is compatible with the `StringFunc` functional interface. Thus, the expression `MyStringOps::strReverse` evaluates to a reference to an object in which `strReverse` provides the implementation of `func()` in `StringFunc`.

### Method References to Instance Methods

To pass a reference to an instance method on a specific object, use this basic syntax:

```
objRef::methodName
```

As you can see, the syntax is similar to that used for a static method, except that an object reference is used instead of a class name. Here is the previous program rewritten to use an instance method reference:
// Demonstrate a method reference to an instance method

// A functional interface for string operations.
interface StringFunc {
    String func(String n);
}

// Now, this class defines an instance method called strReverse().
class MyStringOps {
    String strReverse(String str) {
        String result = "";
        int i;

        for(i = str.length()-1; i >= 0; i--)
            result += str.charAt(i);

        return result;
    }
}

class MethodRefDemo2 {

    // This method has a functional interface as the type of
    // its first parameter. Thus, it can be passed any instance
    // of that interface, including method references.
    static String stringOp(StringFunc sf, String s) {
        return sf.func(s);
    }

    public static void main(String args[]) {
        String inStr = "Lambdas add power to Java";
        String outStr;

        // Create a MyStringOps object.
        MyStringOps strOps = new MyStringOps();

        // Now, a method reference to the instance method strReverse
        // is passed to stringOp().
        outStr = stringOp(strOps::strReverse, inStr);

        System.out.println("Original string: " + inStr);
        System.out.println("String reversed: " + outStr);
    }
}
This program produces the same output as the previous version.

In the program, notice that `strReverse()` is now an instance method of `MyStringOps`. Inside `main()`, an instance of `MyStringOps` called `strOps` is created. This instance is used to create the method reference to `strReverse` in the call to `stringOp`, as shown again, here:

```java
outStr = stringOp(strOps::strReverse, inStr);
```

In this example, `strReverse()` is called on the `strOps` object.

It is also possible to handle a situation in which you want to specify an instance method that can be used with any object of a given class—not just a specified object. In this case, you will create a method reference as shown here:

```java
ClassName::instanceMethodName
```

Here, the name of the class is used instead of a specific object, even though an instance method is specified. With this form, the first parameter of the functional interface matches the invoking object and the second parameter matches the parameter specified by the method. Here is an example. It defines a method called `counter()` that counts the number of objects in an array that satisfy the condition defined by the `func()` method of the `MyFunc` functional interface. In this case, it counts instances of the `HighTemp` class.
// Use an instance method reference with different objects.
// A functional interface that takes two reference arguments
// and returns a boolean result.
interface MyFunc<T> {
    boolean func(T v1, T v2);
}

// A class that stores the temperature high for a day.
class HighTemp {
    private int hTemp;
    HighTemp(int ht) { hTemp = ht; }
    // Return true if the invoking HighTemp object has the same
    // temperature as ht2.
    boolean sameTemp(HighTemp ht2) {
        return hTemp == ht2.hTemp;
    }
    // Return true if the invoking HighTemp object has a temperature
    // that is less than ht2.
    boolean lessThanTemp(HighTemp ht2) {
        return hTemp < ht2.hTemp;
    }
}

class InstanceMethWithObjectRefDemo {
    // A method that returns the number of occurrences
    // of an object for which some criteria, as specified by
    // the MyFunc parameter, is true.
    static <T> int counter(T[] vals, MyFunc<T> f, T v) {
        int count = 0;
        for(int i=0; i < vals.length; i++)
            if(f.func(vals[i], v)) count++;
        return count;
    }

    public static void main(String args[])
    {
        int count;
        // Create an array of HighTemp objects.
        HighTemp[] weekDayHighs = { new HighTemp(89), new HighTemp(82),
                                    new HighTemp(90), new HighTemp(89),
                                    new HighTemp(89), new HighTemp(91),
                                    new HighTemp(84), new HighTemp(83) };
        // Use counter() with arrays of the class HighTemp.
        // Notice that a reference to the instance method
        // sameTemp() is passed as the second argument.
        count = counter(weekDayHighs, HighTemp::sameTemp,
                        new HighTemp(89));
        System.out.println(count + " days had a high of 89");
        // Now, create and use another array of HighTemp objects.
        HighTemp[] weekDayHighs2 = { new HighTemp(32), new HighTemp(12),
                                    new HighTemp(24), new HighTemp(19),
                                    new HighTemp(18), new HighTemp(12),
                                    new HighTemp(-1), new HighTemp(13) };
        count = counter(weekDayHighs2, HighTemp::sameTemp,
                        new HighTemp(12));
        System.out.println(count + " days had a high of 12");
        // Now, use lessThanTemp() to find days when temperature was less
        // than a specified value.
        count = counter(weekDayHighs, HighTemp::lessThanTemp,
                        new HighTemp(89));
        System.out.println(count + " days had a high less than 89");
        count = counter(weekDayHighs2, HighTemp::lessThanTemp,
                        new HighTemp(19));
        System.out.println(count + " days had a high of less than 19");
    }
}
In the program, notice that `HighTemp` has two instance methods: `sameTemp()` and `lessThanTemp()`. The first returns `true` if two `HighTemp` objects contain the same temperature. The second returns `true` if the temperature of the invoking object is less than that of the passed object. Each method has a parameter of type `HighTemp` and each method returns a `boolean` result. Thus, each is compatible with the `MyFunc` functional interface because the invoking object type can be mapped to the first parameter of `func()` and the argument mapped to `func()`’s second parameter. Thus, when the expression

```
HighTemp::sameTemp
```

is passed to the `counter()` method, an instance of the functional interface `MyFunc` is created in which the parameter type of the first parameter is that of the invoking object of the instance method, which is `HighTemp`. The type of the second parameter is also `HighTemp` because that is the type of the parameter to `sameTemp()`. The same is true for the `lessThanTemp()` method.

One other point: you can refer to the superclass version of a method by use of `super`, as shown here:

```
super::name
```

The name of the method is specified by `name`. Another form is

```
typeName.super::name
```

where `typeName` refers to an enclosing class or super interface.

### Method References with Generics

You can use method references with generic classes and/or generic methods. For example, consider the following program:
// Demonstrate a method reference to a generic method
// declared inside a non-generic class.

// A functional interface that operates on an array
// and a value, and returns an int result.
interface MyFunc<T> {
    int func(T[] vals, T v);
}

// This class defines a method called countMatching() that
// returns the number of items in an array that are equal
// to a specified value. Notice that countMatching()
// is generic, but MyArrayOps is not.
class MyArrayOps {
    static <T> int countMatching(T[] vals, T v) {
        int count = 0;

        for(int i=0; i < vals.length; i++)
            if(vals[i] == v) count++;

        return count;
    }
}

class GenericMethodRefDemo {

    // This method has the MyFunc functional interface as the
    // type of its first parameter. The other two parameters
    // receive an array and a value, both of type T.
    static <T> int myOp(MyFunc<T> f, T[] vals, T v) {
        return f.func(vals, v);
    }

    public static void main(String args[]) {
        Integer[] vals = { 1, 2, 3, 4, 2, 3, 4, 4, 5 }; 
        String[] strs = { "One", "Two", "Three", "Two" }; 
        int count;

        count = myOp(MyArrayOps::countMatching, vals, 4); 
        System.out.println("vals contains " + count + " 4s");

        count = myOp(MyArrayOps::countMatching, strs, "Two");
        System.out.println("strs contains " + count + " Twos");
    }
}
In the program, **MyArrayOps** is a non-generic class that contains a generic method called `countMatching()`. The method returns a count of the elements in an array that match a specified value. Notice how the generic type argument is specified. For example, its first call in `main()`, shown here:

```java
count = myOp(MyArrayOps::<Integer>countMatching, vals, 4);
```

passes the type argument `Integer`. Notice that it occurs after the `::`. This syntax can be generalized: When a generic method is specified as a method reference, its type argument comes after the `::` and before the method name. It is important to point out, however, that explicitly specifying the type argument is not required in this situation (and many others) because the type argument would have been automatically inferred. In cases in which a generic class is specified, the type argument follows the class name and precedes the `::`.

Although the preceding examples show the mechanics of using method references, they don’t show their real benefits. One place method references can be quite useful is in conjunction with the Collections Framework, which is described later in Chapter 19. However, for completeness, a short, but effective, example that uses a method reference to help determine the largest element in a collection is included here. (If you are unfamiliar with the Collections Framework, return to this example after you have worked through Chapter 19.)

One way to find the largest element in a collection is to use the `max()` method defined by the **Collections** class. For the version of `max()` used here, you must pass a reference to the collection and an instance of an object that implements the `Comparator<T>` interface. This interface specifies how two objects are compared. It defines only one abstract method, called `compare()`, that takes two arguments, each the type of the objects being compared. It must return greater than zero if the first argument is greater than the second, zero if the two arguments are equal, and less than zero if the first object is less than the second.

In the past, to use `max()` with user-defined objects, an instance of `Comparator<T>` had to be obtained by first explicitly implementing it by a class, and then creating an instance of that class. This instance was then passed as the comparator to `max()`. Beginning with JDK 8, it is now possible to simply pass a reference to a comparison method to `max()` because doing so automatically implements the comparator. The following simple example shows the process by

```java
vals contains 3 4s
strs contains 2 Twos
```
creating an ArrayList of MyClass objects and then finding the one in the list that has the highest value (as defined by the comparison method).

```java
// Use a method reference to help find the maximum value in a collection.
import java.util.*;

class MyClass {
    private int val;
    
    MyClass(int v) { val = v; }
    
    int getVal() { return val; }
}

class UseMethodRef {
    // A compare() method compatible with the one defined by Comparator<T>.
    static int compareMC(MyClass a, MyClass b) {
        return a.getVal() - b.getVal();
    }
    
    public static void main(String args[])
    {
        ArrayList<MyClass> al = new ArrayList<MyClass>();

        al.add(new MyClass(1));
        al.add(new MyClass(4));
        al.add(new MyClass(2));
        al.add(new MyClass(9));
        al.add(new MyClass(3));
        al.add(new MyClass(7));

        // Find the maximum value in al using the compareMC() method.
        MyClass maxValObj = Collections.max(al, UseMethodRef::compareMC);

        System.out.println("Maximum value is: " + maxValObj.getVal());
    }
}
```

The output is shown here:

Maximum value is: 9

In the program, notice that MyClass neither defines any comparison method of its own, nor does it implement Comparator. However, the maximum value of a list of
MyClass items can still be obtained by calling max() because UseMethodRef defines the static method compareMC(), which is compatible with the compare() method defined by Comparator. Therefore, there is no need to explicitly implement and create an instance of Comparator.

Constructor References
Similar to the way that you can create references to methods, you can create references to constructors. Here is the general form of the syntax that you will use:

    classname::new

This reference can be assigned to any functional interface reference that defines a method compatible with the constructor. Here is a simple example:
// Demonstrate a Constructor reference.

// MyFunc is a functional interface whose method returns
// a MyClass reference.
interface MyFunc {
    MyClass func(int n);
}

class MyClass {
    private int val;

    // This constructor takes an argument.
    MyClass(int v) { val = v; }

    // This is the default constructor.
    MyClass() { val = 0; }

    // ...

    int getVal() { return val; }
}

class ConstructorRefDemo {
    public static void main(String args[]) {
        // Create a reference to the MyClass constructor.
        // Because func() in MyFunc takes an argument, new
        // refers to the parameterized constructor in MyClass,
        // not the default constructor.
        MyFunc myClassCons = MyClass::new;

        // Create an instance of MyClass via that constructor reference.
        MyClass mc = myClassCons.func(100);

        // Use the instance of MyClass just created.
        System.out.println("val in mc is "+mc.getVal());
    }
}

The output is shown here:

val in mc is 100

In the program, notice that the `func()` method of `MyFunc` returns a reference of
type **MyClass** and has an **int** parameter. Next, notice that **MyClass** defines two constructors. The first specifies a parameter of type **int**. The second is the default, parameterless constructor. Now, examine the following line:

```cpp
MyFunc myClassCons = MyClass::new;
```

Here, the expression **MyClass::new** creates a constructor reference to a **MyClass** constructor. In this case, because **MyFunc**’s **func()** method takes an **int** parameter, the constructor being referred to is **MyClass(int v)** because it is the one that matches. Also notice that the reference to this constructor is assigned to a **MyFunc** reference called **myClassCons**. After this statement executes, **myClassCons** can be used to create an instance of **MyClass**, as this line shows:

```cpp
MyClass mc = myClassCons.func(100);
```

In essence, **myClassCons** has become another way to call **MyClass(int v)**.

Constructor references to generic classes are created in the same fashion. The only difference is that the type argument can be specified. This works the same as it does for using a generic class to create a method reference: simply specify the type argument after the class name. The following illustrates this by modifying the previous example so that **MyFunc** and **MyClass** are generic.
// Demonstrate a constructor reference with a generic class.

// MyFunc is now a generic functional interface.
interface MyFunc<T> {
    MyClass<T> func(T n);
}

class MyClass<T> {
    private T val;

    // A constructor that takes an argument.
    MyClass(T v) { val = v; }

    // This is the default constructor.
    MyClass() { val = null; }

    // ...

    T getVal() { return val; }
}

class ConstructorRefDemo2 {

    public static void main(String args[]) {
        // Create a reference to the MyClass<T> constructor.
        MyFunc<Integer> myClassCons = MyClass<Integer>::new;

        // Create an instance of MyClass<T> via that constructor reference.
        MyClass<Integer> mc = myClassCons.func(100);

        // Use the instance of MyClass<T> just created.
        System.out.println("val in mc is " + mc.getVal());
    }
}

This program produces the same output as the previous version. The difference is that now both MyFunc and MyClass are generic. Thus, the sequence that creates a constructor reference can include a type argument (although one is not always needed), as shown here:

MyFunc<Integer> myClassCons = MyClass<Integer>::new;

Because the type argument Integer has already been specified when myClassCons
is created, it can be used to create a `MyClass<Integer>` object, as the next line shows:

```java
MyClass<Integer> mc = myClassCons.func(100);
```

Although the preceding examples demonstrate the mechanics of using a constructor reference, no one would use a constructor reference as just shown because nothing is gained. Furthermore, having what amounts to two names for the same constructor creates a confusing situation (to say the least). However, to give you the flavor of a more practical usage, the following program uses a `static` method, called `myClassFactory()`, that is a factory for objects of any type of `MyFunc` objects. It can be used to create any type of object that has a constructor compatible with its first parameter.
// Implement a simple class factory using a constructor reference.

interface MyFunc<R, T> {
    R func(T n);
}

// A simple generic class.
class MyClass<T> {
    private T val;

    // A constructor that takes an argument.
    MyClass(T v) { val = v; }

    // The default constructor. This constructor
    // is NOT used by this program.
    MyClass() { val = null; }

    // ...

    T getVal() { return val; }
}

// A simple, non-generic class.
class MyClass2 {
    String str;

    // A constructor that takes an argument.
    MyClass2(String s) { str = s; }

    // The default constructor. This
    // constructor is NOT used by this program.
    MyClass2() { str = ""; }

    // ...

    String getVal() { return str; }
}

class ConstructorRefDemo3 {

    // A factory method for class objects. The class must
    // have a constructor that takes one parameter of type T.
    // R specifies the type of object being created.
    static <R,T> R myClassFactory(MyFunc<R, T> cons, T v) {
        return cons.func(v);
    }

    public static void main(String args[]) {
        // Create a reference to a MyClass constructor.
        // In this case, new refers to the constructor that
        // takes an argument.
        MyFunc<MyClass<Double>, Double> myClassCons = MyClass<Double>::new;

        // Create an instance of MyClass by use of the factory method.
        MyClass<Double> mc = myClassFactory(myClassCons, 100.1);

        // Use the instance of MyClass just created.
        System.out.println("val in mc is " + mc.getVal( ));

        // Now, create a different class by use of myClassFactory().
        MyFunc<MyClass2, String> myClassCons2 = MyClass2::new;

        // Create an instance of MyClass2 by use of the factory method.
        MyClass2 mc2 = myClassFactory(myClassCons2, "Lambda");

        // Use the instance of MyClass just created.
        System.out.println("str in mc2 is " + mc2.getVal( ));
    }
}
As you can see, `myClassFactory()` is used to create objects of type `MyClass<Double>` and `MyClass2`. Although both classes differ, for example `MyClass` is generic and `MyClass2` is not, both can be created by `myClassFactory()` because they both have constructors that are compatible with `func()` in `MyFunc`. This works because `myClassFactory()` is passed the constructor for the object that it builds. You might want to experiment with this program a bit, trying different classes that you create. Also try creating instances of different types of `MyClass` objects. As you will see, `myClassFactory()` can create any type of object whose class has a constructor that is compatible with `func()` in `MyFunc`. Although this example is quite simple, it hints at the power that constructor references bring to Java.

Before moving on, it is important to mention a second form of the constructor reference syntax that is used for arrays. To create a constructor reference for an array, use this construct:

```
type[]::new
```

Here, `type` specifies the type of object being created. For example, assuming the form of `MyClass` as shown in the first constructor reference example (`ConstructorRefDemo`) and given the `MyArrayCreator` interface shown here:

```java
interface MyArrayCreator<T> {
    T func(int n);
}
```

the following creates a two-element array of `MyClass` objects and gives each element an initial value:

```java
MyArrayCreator<MyClass[]> mcArrayCons = MyClass[]::new;
MyClass[] a = mcArrayCons.func(2);
a[0] = new MyClass(1);
a[1] = new MyClass(2);
```

Here, the call to `func(2)` causes a two-element array to be created. In general, a functional interface must contain a method that takes a single `int` parameter if it is to be used to refer to an array constructor.
Predefined Functional Interfaces

Up to this point, the examples in this chapter have defined their own functional interfaces so that the fundamental concepts behind lambda expressions and functional interfaces could be clearly illustrated. However, in many cases, you won’t need to define your own functional interface because the package called `java.util.function` provides several predefined ones. Although we will look at them more closely in Part II, here is a sampling:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Purpose</th>
</tr>
</thead>
</table>
| UnaryOperator<T>   | Apply a unary operation to an object of type T and return the result, which is also of type T. Its method is called `apply()`.
| BinaryOperator<T>  | Apply an operation to two objects of type T and return the result, which is also of type T. Its method is called `apply()`.
| Consumer<T>        | Apply an operation on an object of type T. Its method is called `accept()`.
| Supplier<T>        | Return an object of type T. Its method is called `get()`.
| Function<T, R>     | Apply an operation to an object of type T and return the result as an object of type R. Its method is called `apply()`.
| Predicate<T>       | Determine if an object of type T fulfills some constraint. Return a `boolean` value that indicates the outcome. Its method is called `test()`.

The following program shows the `Function` interface in action by using it to rework the earlier example called `BlockLambdaDemo` that demonstrated block lambdas by implementing a factorial example. That example created its own functional interface called `NumericFunc`, but the built-in `Function` interface could have been used, as this version of the program illustrates:
// Use the Function built-in functional interface.

// Import the Function interface.
import java.util.function.Function;

class UseFunctionInterfaceDemo {
    public static void main(String args[])
    {
        // This block lambda computes the factorial of an int value.
        // This time, Function is the functional interface.
        Function<Integer, Integer> factorial = (n) -> {
            int result = 1;
            for(int i=1; i <= n; i++)
                result = i * result;
            return result;
        };

        System.out.println("The factorial of 3 is " + factorial.apply(3));
        System.out.println("The factorial of 5 is " + factorial.apply(5));
    }
}

It produces the same output as previous versions of the program.
CHAPTER
With the release of JDK 9 a new and important feature called modules was added to Java. Modules give you a way to describe the relationships and dependencies of the code that comprises an application. Modules also let you control which parts of a module are accessible to other modules and which are not. Through the use of modules you can create more reliable, scalable programs.

As a general rule, modules are most helpful to large applications because they help reduce the management complexity often associated with a large software system. However, small programs also benefit from modules because the Java API library has now been organized into modules. Thus, it is now possible to specify which parts of the API are required by your program and which are not. This makes it possible to deploy programs with a smaller run-time footprint, which is especially important when creating code for small devices, such as those intended to be part of the Internet of Things (IoT).

Support for modules is provided both by language elements, including new keywords, and by enhancements to javac, java, and other JDK tools. Furthermore, new tools and file formats have been introduced. As a result, the JDK and the run-time system provided by JDK 9 have been substantially upgraded to support modules. In short, modules constitute a major addition to, and evolution of, the Java language.

Module Basics

In its most fundamental sense, a module is a grouping of packages and resources that can be collectively referred to by the module’s name. A module declaration specifies the name of a module and defines the relationship a module and its packages have to other modules. Module declarations are program statements in a Java source file and are supported by several new module-related keywords. They are shown here:

<table>
<thead>
<tr>
<th>exports</th>
<th>module</th>
<th>open</th>
<th>opens</th>
</tr>
</thead>
<tbody>
<tr>
<td>provides</td>
<td>requires</td>
<td>to</td>
<td>transitive</td>
</tr>
<tr>
<td>uses</td>
<td>with</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is important to understand that these keywords are recognized as keywords only in
the context of a module declaration. Otherwise, they are interpreted as identifiers in other situations. Thus, the keyword `module` could, for example, also be used as a parameter name, although such a use is certainly not recommended. However, making the module-related keywords context-sensitive prevents problems with pre-existing code that may use one or more of them as identifiers. Because they are context-sensitive, the module-related keywords are formally called restricted keywords.

A module declaration is contained in a file called `module-info.java`. Thus, a module is defined in a Java source file. This file is then compiled by `javac` into a class file and is known as its module descriptor. The `module-info.java` file must contain only a module definition. It cannot contain other types of declarations.

A module declaration begins with the keyword `module`. Here is its general form:

```java
module moduleName {
   // module definition
}
```

The name of the module is specified by `moduleName`, which must be a valid Java identifier or a sequence of identifiers separated by periods. The module definition is specified within the braces. Although a module definition may be empty (which results in a declaration that simply names the module), typically it specifies one or more clauses that define the characteristics of the module.

**A Simple Module Example**

At the foundation of a module’s capabilities are two key features. The first is a module’s ability to specify that it requires another module. In other words, one module can specify that it depends on another. A dependence relationship is specified by use of a `requires` statement. By default, the presence of the required module is checked at both compile time and at run time. The second key feature is a module’s ability to control which, if any, of its packages are accessible by another module. This is accomplished by use of the `exports` keyword. The public and protected types within a package are accessible to other modules only if they are explicitly exported. Here we will develop an example that introduces both of these features.

The following example creates a modular application that demonstrates some simple mathematical functions. Although this application is purposely very small, it illustrates the core concepts and procedures required to create, compile, and run module-based code. Furthermore, the general approach shown here also applies to larger, real-world applications. It is strongly recommended that you work through
the example on your computer, carefully following each step.

NOTE This chapter shows the process of creating, compiling, and running module-based code by use of the command-line tools. This approach has two advantages. First, it works for all Java programmers because no IDE is required. Second, it very clearly shows the fundamentals of the module system, including how it utilizes directories. To follow along, you will need to manually create a number of directories and ensure that each file is placed in its proper directory. As you might expect, when creating real-world, module-based applications you will likely find a module-aware IDE easier to use because, typically, it will automate much of the process. However, learning the fundamentals of modules using the command-line tools ensures that you have a solid understanding of the topic.

The application defines two modules. The first module is called appstart. It contains a package called appstart.mymodappdemo that defines the application’s entry point in a class called MyModAppDemo. Thus, MyModAppDemo contains the application’s main() method. The second module is called appfuncs. It contains a package called appfuncs.simplefuncs that includes the class SimpleMathFuncs. This class defines three static methods that implement some simple mathematical functions. The entire application will be contained in a directory tree that begins at mymodapp.

Before continuing, a few words about module names are appropriate. First, in the examples that follow, the name of a module (such as appfuncs) is the prefix of the name of a package (such as appfuncs.simplefuncs) that it contains. This is not required, but is used here as a way of clearly indicating to what module a package belongs. In general, when learning about and experimenting with modules, short, simple names, such as those used in this chapter, are helpful, and you can use any sort of convenient names that you like. However, when creating modules suitable for distribution, you must be careful with the names you choose because you will want those names to be unique. At the time of this writing, the suggested way to achieve this is to use the reverse domain name method. In this method, the reverse domain name of the domain that “owns” the project is used as a prefix for the module. For example, a project associated with herbschildt.com would use com.herbschildt as the module prefix. (The same goes for package names.) Because modules are a new addition to Java, naming conventions may evolve over time. You will want to check the Java documentation for current recommendations.

Let’s now begin. Start by creating the necessary source code directories by following these steps:
1. Create a directory called `mymodapp`. This is the top-level directory for the entire application.

2. Under `mymodapp`, create a subdirectory called `appsrc`. This is the top-level directory for the application’s source code.

3. Under `appsrc`, create the subdirectory `appstart`. Under this directory, create a subdirectory also called `appstart`. Under this directory, create the directory `mymodappdemo`. Thus, beginning with `appsrc`, you will have created this tree:

   `appsrc\appstart\appstart\mymodappdemo`

4. Also under `appsrc`, create the subdirectory `appfuncs`. Under this directory, create a subdirectory also called `appfuncs`. Under this directory, create the directory called `simplefuncs`. Thus, beginning with `appsrc`, you will have created this tree:

   `appsrc\appfuncs\appfuncs\simplefuncs`

Your directory tree should look like that shown here.

```
mymodapp
  |___ appsrc
      |___ appstart
      |___ appfuncs
          |___ appstart
          |___ appfuncs
              |___ mymodappdemo
              |___ simplefuncs
```

After you have set up these directories, you can create the application’s source files. This example will use four source files. Two are the source files that define the
application. The first is SimpleMathFuncs.java, shown here. Notice that SimpleMathFuncs is packaged in appfuncs.simplefuncs.
// Some simple math functions.

package appfuncs.simplefuncs;

public class SimpleMathFuncs {

    // Determine if a is a factor of b.
    public static boolean isFactor(int a, int b) {
        if((b%a) == 0) return true;
        return false;
    }

    // Return the smallest positive factor that a and b have in common.
    public static int lcf(int a, int b) {
        // Factor using positive values.
        a = Math.abs(a);
        b = Math.abs(b);

        int min = a < b ? a : b;

        for(int i = 2; i <= min/2; i++) {
            if(isFactor(i, a) && isFactor(i, b))
                return i;
        }

        return 1;
    }

    // Return the largest positive factor that a and b have in common.
    public static int gcf(int a, int b) {
        // Factor using positive values.
        a = Math.abs(a);
        b = Math.abs(b);

        int min = a < b ? a : b;

        for(int i = min/2; i >= 2; i--) {
            if(isFactor(i, a) && isFactor(i, b))
                return i;
        }

        return 1;
    }
}
**SimpleMathFuncs** defines three simple static math functions. The first, **isFactor()**, returns true if a is a factor of b. The **lcf()** method returns the smallest factor common to both a and b. In other words, it returns the least common factor of a and b. The **gcf()** method returns the greatest common factor of a and b. In both cases, 1 is returned if no common factors are found. This file must be put in the following directory:

```
appsrc\appfuncts\appfuncts\simplefuncts
```

This is the **appfuncts.simplefuncts** package directory.

The second source file is **MyModAppDemo.java**, shown next. It uses the methods in **SimpleMathFuncs**. Notice that it is packaged in **appstart.mymodappdemo**. Also note that it imports the **SimpleMathFuncs** class because it depends on **SimpleMathFuncs** for its operation.

```java
// Demonstrate a simple module-based application.
package appstart.mymodappdemo;

import appfuncts.simplefuncts.SimpleMathFuncs;

public class MyModAppDemo {
    public static void main(String[] args) {

        if(SimpleMathFuncs.isFactor(2, 10))
            System.out.println("2 is a factor of 10");

        System.out.println("Smallest factor common to both 35 and 105 is " +
            SimpleMathFuncs.lcf(35, 105));

        System.out.println("Largest factor common to both 35 and 105 is " +
            SimpleMathFuncs.gcf(35, 105));

    }
}
```

This file must be put in the following directory:

```
appsrc\appstart\appstart\mymodappdemo
```

This is the directory for the **appstart.mymodappdemo** package.

Next, you will need to add **module-info.java** files for each module. These files contain the module definitions. First, add this one, which defines the **appfuncts** module:
Notice that `appfuncs` exports the package `appfuncs.simplefuncs`, which makes it accessible to other modules. This file must be put into this directory:

```
appsrc\appfuncs
```

Thus, it goes in the `appfuncs` module directory, which is above the package directories.

Finally, the `module-info.java` file for the `appstart` module is shown next. Notice that `appstart` requires the module `appfuncs`.

```
// Module definition for the main application module.
module appstart {
    // Requires the module appfuncs.
    requires appfuncs;
}
```

This file must be put into its module directory:

```
appsrc\appstart
```

Before examining the `requires`, `exports`, and `module` statements more closely, let’s first compile and run this example. Be sure that you have correctly created the directories and entered each file into its proper directory, as just explained.

**Compile and Run the First Module Example**

Beginning with JDK 9, `javac` has been updated to support modules. Thus, like all other Java programs, module-based programs are compiled using `javac`. The process is easy, with the primary difference being that you will usually explicitly specify a *module path*. A module path tells the compiler where the compiled files will be located. When following along with this example, be sure that you execute the `javac` commands from the `mymodapp` directory in order for the paths to be correct. Recall that `mymodapp` is the top-level directory for the entire module application.

To begin, compile `SimpleMathFuncs.java` using this command:

```
javac -d appmodules\appfuncs
appsrc\appfuncs\appfuncs\simplefuncs\SimpleMathFuncs.java
```
Remember, this command must be executed from the mymodapp directory. Notice the use of the -d option. This tells javac where to put the output .class file. For the examples in this chapter, the top of the directory tree for compiled code is appmodules. This command will create the output package directories for appfuncs.simplefuncs under appmodules\appfuncs as needed.

Next, here is the javac command that compiles the module-info.java file for the appfuncs module:

```
javac -d appmodules\appfuncs appsrc\appfuncs\module-info.java
```

This puts the module-info.class file into the appmodules\appfuncs directory.

Although the preceding two-step process works, it was shown primarily for the sake of discussion. It is usually easier to compile a module’s module-info.java file and its source files in one command line. Here, the preceding two javac commands are combined into one:

```
javac -d appmodules\appfuncs appsrc\appfuncs\module-info.java
     appsrc\appfuncs\appfuncs\simplefuncs\SimpleMathFuncs.java
```

In this case, each compiled file is put in its proper module or package directory.

Now, compile module-info.java and MyModAppDemo.java for the appstart module, using this command:

```
javac --module-path appmodules -d appmodules\appstart
     appsrc\appstart\module-info.java
     appsrc\appstart\appstart\mymodappdemo\MyModAppDemo.java
```

Notice the --module-path option. It specifies the module path, which is the path on which the compiler will look for the user-defined modules required by the module-info.java file. In this case, it will look for the appfuncs module because it is needed by the appstart module. Also, notice that it specifies the output directory as appmodules\appstart. This means that the module-info.class file will be in the appmodules\appstart module directory and MyModAppDemo.class will be in the appmodules\appstart\appstart\mymodappdemo package directory.

Once you have completed the compilation, you can run the application with this java command:

```
java --module-path appmodules -m appstart/appstart.mymodappdemo.MyModAppDemo
```

Here, the --module-path option specifies the path to the application’s modules. As mentioned, appmodules is the directory at the top of the compiled modules tree. The -m option specifies the class that contains the entry point of the application and, in
In this case, the name of the class that contains the `main()` method. When you run the program, you will see the following output:

```
2 is a factor of 10
Smallest factor common to both 35 and 105 is 5
Largest factor common to both 35 and 105 is 7
```

A Closer Look at requires and exports

The preceding module-based example relies on the two foundational features of the module system: the ability to specify a dependence and the ability to satisfy that dependence. These capabilities are specified through the use of the `requires` and `exports` statements within a `module` declaration. Each merits a closer examination at this time.

Here is the form of the `requires` statement used in the example:

```
requires moduleName;
```

Here, `moduleName` specifies the name of a module that is required by the module in which the `requires` statement occurs. This means that the required module must be present in order for the current module to compile. In the language of modules, the current module is said to `read` the module specified in the `requires` statement. When more than one module is required, it must be specified in its own `requires` statement. Thus, a module declaration may include several different `requires` statements. In general, the `requires` statement gives you a way to ensure that your program has access to the modules that it needs.

Here is the general form of the `exports` statement used in the example:

```
exports packageName;
```

Here, `packageName` specifies the name of the package that is exported by the module in which this statement occurs. A module can export as many packages as needed, with each one specified in a separate `exports` statement. Thus, a module may have several `exports` statements.

When a module exports a package, it makes all of the public and protected types in the package accessible to other modules. Furthermore, the public and protected members of those types are also accessible. However, if a package within a module is not exported, then it is private to that module, including all of its public types. For example, even though a class is declared as `public` within a package, if that package is not explicitly exported by an `exports` statement, then that class is not accessible to other modules. It is important to understand that the public and protected types of a package, whether exported or not, are always accessible within that package’s module. The `exports` statement simply makes them accessible to outside modules. Thus, any nonexported package is only for the internal use of its module.
The key to understanding requires and exports is that they work together. If one module depends on another, then it must specify that dependence with requires. The module on which another depends must explicitly export (i.e., make accessible) the packages that the dependent module needs. If either side of this dependence relationship is missing, the dependent module will not compile. As it relates to the foregoing example, MyModAppDemo uses the functions in SimpleMathFuncs. As a result, the appstart module declaration contains a requires statement that names the appfuncs module. The appfuncs module declaration exports the appfuncs.simplefuncs package, thus making the public types in the SimpleMathFuncs class available. Since both sides of the dependence relationship have been fulfilled, the application can compile and run. If either is missing, the compilation will fail.

It is important to emphasize that requires and exports statements must occur only within a module statement. Furthermore, a module statement must occur by itself in a file called module-info.java.

java.base and the Platform Modules

As mentioned at the start of this chapter, beginning with JDK 9 the Java API packages have been incorporated into modules. In fact, the modularization of the API is one of the primary benefits realized by the addition of the modules. Because of their special role, the API modules are referred to as platform modules, and their names all begin with the prefix java. Here are some examples: java.base, java.desktop, and java.xml. By modularizing the API, it becomes possible to deploy an application with only the packages that it requires, rather than the entire Java Runtime Environment (JRE). Because of the size of the full JRE, this is a very important improvement.

The fact that all of the Java API library packages are now in modules gives rise to the following question: How can the main() method in MyModAppDemo in the preceding example use System.out.println() without specifying a requires statement for the module that contains the System class? Obviously, the program will not compile and run unless System is present. The same question also applies to the use of the Math class in SimpleMathFuncs. The answer to this question is found in java.base.

Of the platform modules, the most important is java.base. It includes and exports those packages fundamental to Java, such as java.lang, java.io, and java.util, among many others. Because of its importance, java.base is automatically accessible to all modules. Furthermore, all other modules automatically require java.base. There is no need to include a requires java.base statement in a module
declaration. (As a point of interest, it is not wrong to explicitly specify `java.base`, it’s just not necessary.) Thus, in much the same way that `java.lang` is automatically available to all programs without the use of an `import` statement, the `java.base` module is automatically accessible to all module-based programs without explicitly requesting it.

Because `java.base` contains the `java.lang` package, and `java.lang` contains the `System` class, `MyModAppDemo` in the preceding example can automatically use `System.out.println()` without an explicit `requires` statement. The same applies to the use of the `Math` class in `SimpleMathFuncs`, because the `Math` class is also in `java.lang`. As you will see when you begin to create your own module-based applications, many of the API classes you will commonly need are in the packages included in `java.base`. Thus, the automatic inclusion of `java.base` simplifies the creation of module-based code because Java’s core packages are automatically accessible.

One last point: Beginning with JDK 9, the documentation for the Java API now tells you the name of the module in which a package is contained. If the module is `java.base`, then you can use the contents of that package directly. Otherwise, your module declaration must include a `requires` clause for the desired module.

**Legacy Code and the Unnamed Module**

Another question may have occurred to you when working through the first example module program. Because JDK 9 now supports modules, and the API packages are also contained in modules, why do all of the other programs in the preceding chapters compile and run without error even though they do not use modules? More generally, since there is now over 20 years of Java code in existence and (at the time of this writing) the vast majority of that code does not use modules, how is it possible to compile, run, and maintain that legacy code with a JDK 9 or later compiler? Given Java’s original philosophy of “write once, run everywhere,” this is a very important question because backward capability must be maintained. As you will see, Java answers this question by providing an elegant, nearly transparent means of ensuring backward compatibility with pre-existing code.

Support for legacy code is provided by two key features. The first is the **unnamed module**. When you use code that is not part of a named module, it automatically becomes part of the unnamed module. The unnamed module has two important attributes. First, all of the packages in the unnamed module are automatically exported. Second, the unnamed module can access any and all other modules. Thus, when a program does not use modules, all API modules in the Java platform are automatically accessible through the unnamed module.
The second key feature that supports legacy code is the automatic use of the class path, rather than the module path. When you compile a program that does not use modules, the class path mechanism is employed, just as it has been since Java’s original release. As a result, the program is compiled and run in the same way it was prior to JDK 9.

Because of the unnamed module and the automatic use of the class path, there was no need to declare any modules for the sample programs shown elsewhere in this book. They run properly whether you compile them with a JDK 9 compiler or an earlier one, such as JDK 8. Thus, even though modules are a new feature that has significant impact on Java, compatibility with legacy code is maintained. This approach also provides a smooth, nonintrusive, nondisruptive transition path to modules. Thus, it enables you to move a legacy application to modules at your own pace. Furthermore, it allows you to avoid the use of modules when they are not needed.

Before moving on, an important point needs to be made. For the types of example programs used elsewhere in this book, and for example programs in general, there is no benefit in using modules. Modularizing them would simply add clutter and complicate them for no reason or benefit. Furthermore, for many simple programs, there is no need to contain them in modules. For the reasons stated at the start of this chapter, modules are often of the greatest benefit when creating commercial programs. Therefore, no examples outside this chapter will use modules. This also allows the examples to be compiled and run in a pre–JDK 9 environment, which is important to readers using an older version of Java. Thus, except for the examples in this chapter, the examples in this book work for both pre-module and post-module JDKs.

Exporting to a Specific Module

The basic form of the exports statement makes a package accessible to any and all other modules. This is often exactly what you want. However, in some specialized development situations, it can be desirable to make a package accessible to only a specific set of modules, not all other modules. For example, a library developer might want to export a support package to certain other modules within the library, but not make it available for general use. Adding a to clause to the exports statement provides a means by which this can be accomplished.

In an exports statement, the to clause specifies a list of one or more modules that have access to the exported package. Furthermore, only those modules named in the to clause will have access. In the language of modules, the to clause creates what is known as a qualified export.
The form of **exports** that includes **to** is shown here:

```java
exports packageName to moduleNames;
```

Here, **moduleNames** is a comma-separated list of modules to which the exporting module grants access.

You can try the **to** clause by changing the **module-info.java** file for the **appfuncs** module, as shown here:

```java
// Module definition that uses a to clause.
module appfuncs {
   // Exports the package appfuncs.simplefuncs to appstart.
   exports appfuncs.simplefuncs to appstart;
}
```

Now, **simplefuncs** is exported only to **appstart** and to no other modules. After making this change, you can recompile the application by using this **javac** command:

```bash
javac -d appmodules --module-source-path appsrc
   appsrc\appstart\appstart\mymodappdemo\MyModAppDemo.java
```

After compiling, you can run the application as shown earlier.

This example also uses another new module-related feature provided by JDK 9. Look closely at the preceding **javac** command. First, notice that it specifies the **--module-source-path** option. The module source path specifies the top of the module source tree. The **--module-source-path** option automatically compiles the files in the tree under the specified directory, which is **appsrc** in this example. The **module-source-path** option must be used with the **-d** option to ensure that the compiled modules are stored in their proper directories under **appmodules**. This form of **javac** is called **multi-module mode** because it enables more than one module to be compiled at a time. The multi-module compilation mode is especially helpful here because the **to** clause refers to a specific module, and the requiring module must have access to the exported package. Thus, in this case, both **appstart** and **appfuncs** are needed to avoid warnings and/or errors during compilation. Multi-module mode avoids this problem because both modules are being compiled at the same time.

The multi-module mode of **javac** has another advantage. It automatically finds and compiles all source files for the application, creating the necessary output directories. Because of the advantages that multi-module compilation mode offers, it will be used for the subsequent examples.

---

**NOTE** As a general rule, qualified export is a special case feature. Most often, your modules will either provide unqualified export of a package or not export the
package at all, keeping it inaccessible. As such, qualified export is discussed here primarily for the sake of completeness. Also, qualified export by itself does not prevent the exported package from being misused by malicious code in a module that masquerades as the targeted module. The security techniques required to prevent this from happening are beyond the scope of this book. Consult the Oracle documentation for details on security in this regard, and Java security details in general.

**Using requires transitive**

Consider a situation in which there are three modules, A, B, and C, that have the following dependences:

- A requires B.
- B requires C.

Given this situation, it is clear that since A depends on B and B depends on C, A has an indirect dependence on C. As long as A does not directly use any of the contents of C, then you can simply have A require B in its module-info file, and have B export the packages required by A in its module-info file, as shown here:

```java
// A's module-info file:
module A {
  requires B;
}

// B's module-info file.
module B {
  exports somepack;
  requires C;
}
```

Here, *somepack* is a placeholder for the package exported by B and used by A. Although this works as long as A does not need to use anything defined in C, a problem occurs if A *does* want to access a type in C. In this case, there are two solutions.

The first solution is to simply add a `requires C` statement to A’s file, as shown here:
This solution certainly works, but if B will be used by many modules, you must add requires C to all module definitions that require B. This is not only tedious, it is also error prone. Fortunately, there is a better solution. You can create an implied dependence on C. Implied dependence is also referred to as implied readability.

To create an implied dependence, add the transitive keyword after requires in the clause that requires the module upon which an implied readability is needed. In the case of this example, you would change B’s module-info file as shown here:

```java
// B's module-info file.
module B {
    exports somepack;
    requires transitive C;
}
```

Here, C is now required as transitive. After making this change, any module that depends on B will also, automatically, depend on C. Thus, A would automatically have access to C.

You can experiment with requires transitive by reworking the preceding modular application example so that the isFactor() method is removed from the SimpleMathFuncs class in the appfuncs.simplefuncs package and put into a new class, module, and package. The new class will be called SupportFuncs, the module will be called appsupport, and the package will be called appsupport.supportfuncs. The appfuncs module will then add a dependence on the appsupport module by use of requires transitive. This will enable both the appfuncs and appstart modules to access it without appstart having to provide its own requires statement. This works because appstart receives access to it through an appfuncs requires transitive statement. The following describes the process in detail.

To begin, create the source directories that support the new appsupport module. First, create appsupport under the appsrc directory. This is the module directory for the support functions. Under appsupport, create the package directory by adding the appsupport subdirectory followed by the supportfuncs subdirectory. Thus, the directory tree for appsupport should now look like this:

```
appsrc\appsupport\appsupport\supportfuncs
```
Once the directories have been established, create the SupportFuncs class. Notice that SupportFuncs is part of the appsupport.supportfuncs package. Therefore, you must put it in the appsupport.supportfuncs package directory.

    // Support functions.

    package appsupport.supportfuncs;

    public class SupportFuncs {

        // Determine if a is a factor of b.
        public static boolean isFactor(int a, int b) {
            if((b%a) == 0) return true;
            return false;
        }
    }

Notice that isFactor() is now part of SupportFuncs, rather than SimpleMathFuncs.

Next, create the module-info.java file for the appsupport module and put it in appsrc\appsupport directory.

    // Module definition for appsupport.
    module appsupport {
        exports appsupport.supportfuncs;
    }

As you can see, it exports the appsupport.supportfuncs package.

Because isFactor() is now part of SupportFuncs, remove it from SimpleMathFuncs. Thus, SimpleMathFuncs.java will now look like this:
Notice that now the `SupportFuncs` class is imported and calls to `isFactor()` are referred to through the class name `SupportFuncs`.

Next, change the `module-info.java` file for `appfuncs` so that in its `requires` statement, `appsupport` is specified as `transitive`, as shown here:
Because `appfuncs` requires `appsupport` as transitive, there is no need for the `module-info.java` file for `appstart` to also require it. Its dependence on `appsupport` is implied. Thus, no changes to the `module-info.java` file for `appstart` are needed.

Finally, update `MyModAppDemo.java` to reflect these changes. Specifically, it must now import the `SupportFuncs` class and specify it when invoking `isFactor()`, as shown here:

```java
import appfuncs.simplefuncts.SimpleMathFuncts;
import appsupport.supportfuncts.SupportFuncs;

public class MyModAppDemo {
    public static void main(String[] args) {

        // Now, isFactor() is referred to via SupportFuncs,
        // not SimpleMathFuncts.
        if(SupportFuncs.isFactor(2, 10))
            System.out.println("2 is a factor of 10");

        System.out.println("Smallest factor common to both 35 and 105 is "+
                        SimpleMathFuncts.lcf(35, 105));

        System.out.println("Largest factor common to both 35 and 105 is "+
                        SimpleMathFuncts.gcf(35, 105));
    }
}
```

Once you have completed all of the preceding steps, you can recompile the entire program using this multi-module compilation command:

```
javac -d appmodules --module-source-path appsr
        appsr\appstart\appstart\mymodappdemo\MyModAppDemo.java
```
As explained earlier, the multi-module compilation will automatically create the parallel module subdirectories, under the `appmodules` directory.

You can run the program using this command:

```bash
java --module-path appmodules -m appstart/appstart.mymodappdemo.MyModAppDemo
```

It will produce the same output as the previous version. However, this time three different modules are required.

To prove that the `transitive` modifier is actually required by the application, remove it from the `module-info.java` file for `appfuncs`. Then, try to compile the program. As you will see, an error will result because `appsupport` is no longer accessible by `appstart`.

Here is another experiment. In the module-info file for `appsupport`, try exporting the `appsupport.supportfuncs` package to only `appfuncs` by use of a qualified export, as shown here:

```java
exports appsupport.supportfuncs to appfuncs;
```

Next, attempt to compile the program. As you see, the program will not compile because now the support function `isFactor()` is not available to `MyModAppDemo`, which is in the `appstart` module. As explained previously, a qualified export restricts access to a package to only those modules specified by the `to` clause.

One final point, because of a special exception in the Java language syntax, in a `requires` statement, if `transitive` is immediately followed by a separator (such as a semicolon), it is interpreted as an identifier (for example, as a module name) rather than a keyword.

**Use Services**

In programming, it is often useful to separate what must be done from how it is done. As you learned in Chapter 9, one way this is accomplished in Java is through the use of interfaces. The interface specifies the what, and the implementing class specifies the how. This concept can be expanded so that the implementing class is provided by code that is outside your program, through the use of a plug-in. Using such an approach, the capabilities of an application can be enhanced, upgraded, or altered by simply changing the plug-in. The core of the application itself remains unchanged. One way that Java supports a pluggable application architecture is through the use of services and service providers. Because of their importance, especially in large, commercial applications, Java’s module system provides support for them.

Before we begin, it is necessary to state that applications that use services and
service providers are typically fairly sophisticated. Therefore, you may find that you do not often need the service-based module features. However, because support for services constitutes a rather significant part of the module system, it is important that you have a general understanding of how these features work. Also, a simple example is presented that illustrates the core techniques needed to use them.

**Service and Service Provider Basics**

In Java, a *service* is a program unit whose functionality is defined by an interface or abstract class. Thus, a service specifies in a general way some form of program activity. A concrete implementation of a service is supplied by a *service provider*. In other words, a service defines the form of some action, and the service provider supplies that action.

As mentioned, services are often used to support a pluggable architecture. For example, a service might be used to support the translation of one language into another. In this case, the service supports translation in general. The service provider supplies a specific translation, such as German to English or French to Chinese. Because all service providers implement the same interface, different translators can be used to translate different languages without having to change the core of the application. You can simply change the service provider.

Service providers are supported by the `ServiceLoader` class. `ServiceLoader` is a generic class packaged in `java.util`. It is declared like this:

```java
class ServiceLoader<S>
```

Here, `S` specifies the service type. Service providers are loaded by the `load()` method. It has several forms; the one we will use is shown here:

```java
public static <S> ServiceLoader<S> load(Class <S> serviceType)
```

Here, `serviceType` specifies the `Class` object for the desired service type. Recall that `Class` is a class that encapsulates information about a class. There are a variety of ways to obtain a `Class` instance. The way we will use here involves a class literal. Recall that a class literal has this general form:

```java
className.class
```

Here, `className` specifies the name of the class.

When `load()` is called, it returns a `ServiceLoader` instance for the application. This object supports iteration and can be cycled through by use of a for-each `for` loop. Therefore, to find a specific provider, simply search for it using a loop.

**The Service-Based Keywords**

Modules support services through the use of the keywords `provides`, `uses`, and `with`.
Essentially, a module specifies that it provides a service with a `provides` statement. A module indicates that it requires a service with a `uses` statement. The specific type of service provider is declared by `with`. When used together, they enable you to specify a module that provides a service, a module that needs that service, and the specific implementation of that service. Furthermore, the module system ensures that the service and service providers are available and will be found.

Here is the general form of `provides`:

```
provides serviceType with implementationTypes;
```

Here, `serviceType` specifies the type of the service, which is often an interface, although abstract classes are also used. A comma-separated list of the implementation types is specified by `implementationTypes`. Therefore, to provide a service, the module indicates both the name of the service and its implementation.

Here is the general form of the `uses` statement:

```
uses serviceType;
```

Here, `serviceType` specifies the type of the service required.

### A Module-Based Service Example

To demonstrate the use of services we will add a service to the modular application example that we have been evolving. For simplicity, we will begin with the first version of the application shown at the start of this chapter. To it we will add two new modules. The first is called `userfuncs`. It will define interfaces that support functions that perform binary operations in which each argument is an `int` and the result is an `int`. The second module is called `userfuncsimp`, and it contains concrete implementations of the interfaces.

Begin by creating the necessary source directories.

1. Under the `appsrc` directory add directories called `userfuncs` and `userfuncsimp`.
2. Under `userfuncs`, add the subdirectory also called `userfuncs`. Under that directory, add the subdirectory `binaryfuncs`. Thus, beginning with `appsrc`, you will have created this tree:

```
appsrc\userfuncs\userfuncs\binaryfuncs
```
3. Under `userfuncsimp`, add the subdirectory also called `userfuncsimp`. Under that directory, add the subdirectory `binaryfuncsimp`. Thus, beginning with `appsrc`, you will have created this tree:

```
appsrc\userfuncsimp\userfuncsimp\binaryfuncsimp
```
This example expands the original version of the application by providing support for functions beyond those built into the application. Recall that the `SimpleMathFuncs` class supplies three built-in functions: `isFactor()`, `lcf()`, and `gcf()`. Although it would be possible to add more functions to this class, doing so requires modifying and recompiling the application. By implementing services, it becomes possible to “plug in” new functions at run time, without modifying the application, and that is what this example will do. In this case, the service supplies functions that take two `int` arguments and return an `int` result. Of course, other types of functions can be supported if additional interfaces are provided, but support for binary integer functions is sufficient for our purposes and keeps the source code size of the example manageable.

### The Service Interfaces

Two service-related interfaces are needed. One specifies the form of an action, and the other specifies the form of the provider of that action. Both go in the `binaryfuncs` directory, and both are in the `userfuncs.binaryfuncs` package. The first, called `BinaryFunc`, declares the form of a binary function. It is shown here:

```java
// This interface defines a function that takes two int // arguments and returns an int result. Thus, it can // describe any binary operation on two ints that // returns an int.

package userfuncs.binaryfuncs;

public interface BinaryFunc {
    // Obtain the name of the function.
    public String getName();

    // This is the function to perform. It will be // provided by specific implementations.
    public int func(int a, int b);
}
```

`BinaryFunc` declares the form of an object that can implement a binary integer function. This is specified by the `func()` method. The name of the function is obtainable from `getName()`. The name will be used to determine what type of function is implemented. This interface is implemented by a class that supplies a binary function.

The second interface declares the form of the service provider. It is called `BinFuncProvider` and is shown here:
BinFuncProvider declares only one method, get(), which is used to obtain an instance of BinaryFunc. This interface must be implemented by a class that wants to provide instances of BinaryFunc.

The Implementation Classes
In this example, two concrete implementations of BinaryFunc are supported. The first is AbsPlus, which returns the sum of the absolute values of its arguments. The second is AbsMinus, which returns the result of subtracting the absolute value of the second argument from the absolute value of the first argument. These are provided by the classes AbsPlusProvider and AbsMinusProvider. The source code for these classes must be stored in the binaryfunctsimp directory, and they are all part of the userfunctsimp.binaryfunctsimp package.

The code for AbsPlus is shown here:

```java
// This interface defines the form of a service provider that obtains BinaryFunc instances.
package userfunctsimp.binaryfunctsimp;

import userfunctsimp.binaryfunctsimp.BinaryFunc;

public interface BinFuncProvider {

    // Obtain a BinaryFunc.
    public BinaryFunc get();
}

BinFuncProvider declares only one method, get(), which is used to obtain an instance of BinaryFunc. This interface must be implemented by a class that wants to provide instances of BinaryFunc.

The Implementation Classes
In this example, two concrete implementations of BinaryFunc are supported. The first is AbsPlus, which returns the sum of the absolute values of its arguments. The second is AbsMinus, which returns the result of subtracting the absolute value of the second argument from the absolute value of the first argument. These are provided by the classes AbsPlusProvider and AbsMinusProvider. The source code for these classes must be stored in the binaryfunctsimp directory, and they are all part of the userfunctsimp.binaryfunctsimp package.

The code for AbsPlus is shown here:

```java
// AbsPlus provides a concrete implementation of BinaryFunc. It returns the result of abs(a) + abs(b).
package userfunctsimp.binaryfunctsimp;

import userfunctsimp.binaryfunctsimp.BinaryFunc;

public class AbsPlus implements BinaryFunc {

    // Return name of this function.
    public String getName() {
        return "absPlus";
    }

    // Implement the AbsPlus function.
    public int func(int a, int b) { return Math.abs(a) + Math.abs(b); }
}
AbsPlus implements `func()` such that it returns the result of adding the absolute values of `a` and `b`. Notice that `getName()` returns the "absPlus" string. It identifies this function.

The AbsMinus class is shown next:

```java
// AbsMinus provides a concrete implementation of
// BinaryFunc. It returns the result of abs(a) - abs(b).

package userfuncs.imp.binaryfuncsimp;
import userfuncs.binaryfuncts.BinaryFunc;

public class AbsMinus implements BinaryFunc {

    // Return name of this function.
    public String getName() {
        return "absMinus";
    }

    // Implement the AbsMinus function.
    public int func(int a, int b) { return Math.abs(a) - Math.abs(b); }
}
```

Here, `func()` is implemented to return the difference between the absolute values of `a` and `b`, and the string "absMinus" is returned by `getName()`.

To obtain an instance of AbsPlus, the AbsPlusProvider is used. It implements BinFuncProvider and is shown here:

```java
// This is a provider for the AbsPlus function.

package userfuncs.imp.binaryfuncsimp;
import userfuncs.binaryfuncts.*;

public class AbsPlusProvider implements BinFuncProvider {

    // Provide an AbsPlus object.
    public BinaryFunc get() { return new AbsPlus(); }
}
```

The `get()` method simply returns a new `AbsPlus()` object. Although this provider is very simple, it is important to point out that some service providers will be much more complex.
The provider for AbsMinus is called AbsMinusProvider and is shown next:

```java
// This is a provider for the AbsMinus function.
package userfunccsimp.binaryfunccsimp;
import userfunccs.binaryfunccs.*;
public class AbsMinusProvider implements BinFuncProvider {
    // Provide an AbsMinus object.
    public BinaryFunc get() { return new AbsMinus(); }
}
```

Its get() method returns an object of AbsMinus.

### The Module Definition Files

Next, two module definition files are needed. The first is for the userfuncs module. It is shown here:

```java
module userfuncs {
    exports userfunccs.binaryfunccs;
}
```

This code must be contained in a module-info.java file that is in the userfuncs module directory. Notice that it exports the userfunccs.binaryfunccs package. This is the package that defines the BinaryFunc and BinFuncProvider interfaces.

The second module-info.java file is shown next. It defines the module that contains the implementations. It goes in the userfunccsimp module directory.

```java
module userfunccsimp {
    requires userfuncs;
    provides userfunccs.binaryfunccs.BinFuncProvider with
    userfunccsimp.binaryfunccsimp.AbsPlusProvider,
    userfunccsimp.binaryfunccsimp.AbsMinusProvider;
}
```

This module requires userfuncs because that is where BinaryFunc and BinFuncProvider are contained, and those interfaces are needed by the implementations. The module provides BinFuncProvider implementations with the classes AbsPlusProvider and AbsMinusProvider.
Demonstrate the Service Providers in MyModAppDemo

To demonstrate the use of the services, the `main()` method of `MyModAppDemo` is expanded to use `AbsPlus` and `AbsMinus`. It does so by loading them at run time by use of `ServiceLoader.load()`. Here is the updated code:
// A module-based application that demonstrates services 
// and service providers.

package appstart.mymodappidemo;

import java.util.ServiceLoader;

import appfuncs.simplefuncs.SimpleMathFuncs;
import userfuncs.binaryfuncs.*;

public class MyModAppDemo {
    public static void main(String[] args) {
        // First, use built-in functions as before.
        if(SimpleMathFuncs.isFactor(2, 10))
            System.out.println("2 is a factor of 10");

        System.out.println("Smallest factor common to both 35 and 105 is ") + 
            SimpleMathFuncs.lcf(35, 105));

        System.out.println("Largest factor common to both 35 and 105 is ") + 
            SimpleMathFuncs.gcf(35, 105));

        // Now, use service-based, user-defined operations.

        // Get a service loader for binary functions.
        ServiceLoader<BinFuncProvider> ldr = 
            ServiceLoader.load(BinFuncProvider.class);

        BinaryFunc binOp = null;

        // Find the provider for absPlus and obtain the function.
        for(BinFuncProvider bfp : ldr) {
            if(bfp.get().getName().equals("absPlus")) {
                binOp = bfp.get();
                break;
            }
        }

        if(binOp != null)
            System.out.println("Result of absPlus function: ") + 
                binOp.func(12, -4));
        else
            System.out.println("absPlus function not found");

        binOp = null;

        // Now, find the provider for absMinus and obtain the function.
        for(BinFuncProvider bfp : ldr) {
            if(bfp.get().getName().equals("absMinus")) {
                binOp = bfp.get();
                break;
            }
        }

        if(binOp != null)
            System.out.println("Result of absMinus function: ") + 
                binOp.func(12, -4));
        else
            System.out.println("absMinus function not found");
    }
}
Let’s take a close look at how a service is loaded and executed by the preceding code. First, a service loader for services of type `BinFuncProvider` is created with this statement:

```java
ServiceLoader<BinFuncProvider> ldr =
    ServiceLoader.load(BinFuncProvider.class);
```

Notice that the type parameter to `ServiceLoader` is `BinFuncProvider`. This is also the type used in the call to `load()`. This means that providers that implement this interface will be found. Thus, after this statement executes, `BinFuncProvider` classes in the module will be available through `ldr`. In this case, both `AbsPlusProvider` and `AbsMinusProvider` will be available.

Next, a reference of type `BinaryFunc` called `binOp` is declared and initialized to `null`. It will be used to refer to an implementation that supplies a specific type of binary function. Next, the following loop searches `ldr` for one that has the "absPlus" name.

```java
// Find the provider for absPlus and obtain the function.
for (BinFuncProvider bfp : ldr) {
    if (bfp.getName().equals("absPlus")) {
        binOp = bfp.get();
        break;
    }
}
```

Here, a for-each loop iterates through `ldr`. Inside the loop, the name of the function supplied by the provider is checked. If it matches "absPlus", that function is assigned to `binOp` by calling the provider’s `get()` method.

Finally, if the function is found, as it will be in this example, it is executed by this statement:

```java
if (binOp != null)
    System.out.println("Result of absPlus function: " +
                        binOp.func(12, -4));
```

In this case, because `binOp` refers to an instance of `AbsPlus`, the call to `func()` performs an absolute value addition. A similar sequence is used to find and execute `AbsMinus`.

Because `MyModAppDemo` now uses `BinFuncProvider`, its module definition file must include a `uses` statement that specifies this fact. Recall that `MyModAppDemo` is in the `appstart` module. Therefore, you must change the
module-info.java file for appstart as shown here:

```java
// Module definition for the main application module.
// It now uses BinFuncProvider.
module appstart {
    // Requires the modules appfuncs and userfuncs.
    requires appfuncs;
    requires userfuncs;

    // appstart now uses BinFuncProvider.
    uses userfuncs.binaryfuncts.BinFuncProvider;
}
```

**Compile and Run the Module-Based Service Example**

Once you have performed all of the preceding steps, you can compile and run the example by executing the following commands:

```
javac  -d appmodules --module-source-path appsrcc
    appsrcc\userfuncsimpl\module-info.java
    appsrcc\appstart\appstart\mymodappdemo\MyModAppDemo.java
```

```
java --module-path appmodules -m appstart/appstart.mymodappdemo.MyModAppDemo
```

Here is the output:

```
2 is a factor of 10
Smallest factor common to both 35 and 105 is 5
Largest factor common to both 35 and 105 is 7
Result of absPlus function: 16
Result of absMinus function: 8
```

As the output shows, the binary functions were located and executed. It is important to emphasize that if either the `provides` statement in the `userfuncsimpl` module or the `uses` statement in the `appstart` module were missing, the application would fail.

One last point: The preceding example was kept very simple in order to clearly illustrate module support for services, but much more sophisticated uses are possible. For example, you might use a service to provide a `sort()` method that sorts a file. Various sorting algorithms could be supported and made available through the service. The specific sort could then be chosen based on the desired run-time characteristics, the nature and/or size of the data, and whether random access to the data is supported. You might want to try implementing such a service as a way to further experiment with services in modules.
Module Graphs

A term you are likely to encounter when working with modules is *module graph*. During compilation, the compiler resolves the dependence relationships between modules by creating a module graph that represents the dependences. The process ensures that *all dependences* are resolved, including those that occur indirectly. For example, if module A requires module B, and B requires module C, then the module graph will contain module C even if A does not use it directly.

Module graphs can be depicted visually in a drawing to illustrate the relationship between modules. Here is a simple example. Assume six modules called A, B, C, D, E, and F. Further assume that A requires B and C, B requires D and E, and C requires F. The following visually depicts this relationship. (Because java.base is automatically included, it is not shown in the diagram.)

In Java, the arrows point from the dependent module to the required module. Thus, a drawing of a module graph depicts what modules have access to what other modules. Frankly, only the smallest applications can have their module graphs visually represented because of the complexity typically involved in many commercial applications.

Three Specialized Module Features

The preceding discussions have described the key features of modules supported by the Java language, and they are the features on which you will typically rely when creating your own modules. However, there are three additional module-related features that can be quite useful in certain circumstances. These are the open module, the opens statement, and the use of requires static. Each of these features is designed to handle a specialized situation, and each constitutes a fairly advanced aspect of the module system. That said, it is important for all Java programmers to have a general understanding of their purpose.
Open Modules
As you learned earlier in this chapter, by default, the types in a module’s packages are accessible only if they are explicitly exported via an `exports` statement. While this is usually what you will want, there can be circumstances in which it is useful to enable run-time access to all packages in the module, whether a package is exported or not. To allow this, you can create an open module. An open module is declared by preceding the `module` keyword with the `open` modifier, as shown here:

```
open module moduleName {
    // module definition
}
```

In an open module, types in all its packages are accessible at run time. Understand, however, that only those packages that are explicitly exported are available at compile time. Thus, the `open` modifier affects only run-time accessibility. The primary reason for an open module is to enable the packages in the module to be accessed through reflection. As explained in Chapter 12, reflection is the feature that lets a program analyze code at run time.

The opens Statement
It is possible for a module to open a specific package for run-time access by other modules and for reflective access rather than opening an entire module. To do so, use the `opens` statement, shown here:

```
opens packageName;
```

Here, `packageName` specifies the package to open. It is also possible to include a `to` clause, which names those modules for which the package is opened.

It is important to understand `opens` does not grant compile-time access. It is used only to open a package for run-time and reflective access. However, you can both export and open a module. One other point: an `opens` statement cannot be used in an open module. Remember, all packages in an open module are already open.

requires static
As you know, `requires` specifies a dependence that, by default, is enforced both during compilation and at run time. However, it is possible to relax this requirement in such a way that a module is not required at run time. This is accomplished by use of the `static` modifier in a `requires` statement. For example, this specifies that `mymod` is required for compilation, but not at run time:
In this case, the addition of static makes mymod optional at run time. This can be helpful in a situation in which a program can utilize functionality if it is present, but not require it.

**Introducing jlink and Module JAR Files**

As the preceding discussions have shown, modules represent a substantial enhancement to the Java language. The module system also supports enhancements at run time. One of the most important is the ability to create a run-time image that is specifically tailored to your application. To accomplish this, JDK 9 adds a new tool called jlink. It combines a group of modules into an optimized run-time image. You can use jlink to link modular JAR files, the new JMOD files, or even modules in their unarchived, “exploded directory” form.

**Linking Files in an Exploded Directory**

Let’s look first at using jlink to create a run-time image from unarchived modules. That is, the files are contained in their raw form in a fully expanded (i.e., exploded) directory. Assuming a Windows environment, the following command links the modules for the first example in this chapter. It must be executed from a directory directly above mymodapp.

```
jlink --launcher MyModApp=appstart/appstart.mymodappdemo.MyModAppDemo
    --module-path "%JAVA_HOME%\jmods;mymodapp\appmodules"
    --add-modules appstart --output mylinkedmodapp
```

Let’s look closely at this command. First, the option --launcher tells jlink to create a command that starts the application. It specifies the name of the application and the path to the main class. In this case, the main class is MyModAppDemo. The --module-path option specifies the path to the required modules. The first is the path to the platform modules; the second is the path to the application modules. Notice the use of the environmental variable JAVA_HOME. It represents the path to the standard JDK directory. For example, in a standard Windows installation, the path will typically be something similar to "C:\program files"\java\jdk-9\jmods, but the use of JAVA_HOME is both shorter and able to work no matter in what directory the JDK was installed. The --add-modules option specifies the module or modules to add. Notice that only appstart is specified. This is because jlink automatically resolves all dependencies and includes all required modules. Finally, --output specifies the output directory.
After you run the preceding command, a directory called mylinkedmodapp will have been created that contains the run-time image. In its bin directory, you will find a launcher file called MyModApp that you can use to run the application. For example, in Windows, this will be a batch file that executes the program.

Linking Modular JAR Files

Although linking modules from their exploded directory is convenient, when working on real-world code you will often be using JAR files. (Recall that JAR stands for Java ARchive. It is a file format typically used for application deployment.) In the case of modular code, you will be using modular JAR files. A modular JAR file is one that contains a module-info.class file. Beginning with JDK 9, the jar tool has the ability to create modular JAR files. For example, it can now recognize a module path. Once you have created modular JAR files, you can use jlink to link them into a run-time image. To understand the process, let’s work through an example. Again assuming the first example in this chapter, here are the jar commands that create modular JAR files for the MyModAppDemo program. Each must be executed from a directory directly above mymodapp. Also, you will need to create a directory called applib under mymodapp.

```
jar --create --file=mymodapp\applib\appfuncs.jar
   -C mymodapp\appmodules\appfuncs .

jar --create --file=mymodapp\applib\appstart.jar
    --main-class=appstart.mymodappdemo.MyModAppDemo
    -C mymodapp\appmodules\appstart .
```

Here, --create tells jar to create a new JAR file. The --file option specifies the name of the JAR file. The files to include are specified by the -C option. The class that contains main() is specified by the --main-class option. After running these commands, the JAR files for the application will be in the applib directory under mymodapp.

Given the modular JAR files just created, here is the command that links them:

```
jlink --launcher MyModApp=appstart
    --module-path "%JAVA_HOME%\jmods;mymodapp\applib
    --add-modules appstart --output mylinkedmodapp
```

Here, the module path to the JAR files is specified, not the path to the exploded directories. Otherwise, the jlink command is the same as before.

As a point of interest, you can use the following command to run the application
directly from the JAR files. It must be executed from a directory directly above `mymodapp`.

```
java -p mymodapp\applib -m appstart
```

Here, `-p` specifies the module path and `-m` specifies the module that contains the program’s entry point.

### JMOD Files

The `jlink` tool can also link files that use the new JMOD format defined by JDK 9. JMOD files can include things that are not applicable to a JAR file. They are created by the new `jmod` tool. Although most applications will still use module JAR files, JMOD files will be of value in specialized situations. As a point of interest, beginning with JDK 9 the platform modules are contained in JMOD files.

### A Brief Word About Layers and Automatic Modules

When learning about modules you are likely to encounter reference to two additional module-related features. These are `layers` and `automatic modules`. Both are designed for specialized, advanced work with modules or when migrating preexisting applications. Although it is likely that most programmers will not need to make use of these features, a brief description of each is given here in the interest of completeness.

A module layer associates the modules in a module graph with a class loader. Thus, different layers can use different class loaders. Layers enable certain specialized types of applications to be more easily constructed.

An automatic module is created by specifying a nonmodular JAR file on the module path, with its name being automatically derived. (It is also possible to explicitly specify a name for an automatic module in the manifest file.) Automatic modules enable normal modules to have a dependence on code in the automatic module. Automatic modules are provided as an aid in migration from pre-modular code to fully modular code. Thus, they are primarily a transitional feature.

### Final Thoughts on Modules

The preceding discussions have introduced and demonstrated the core elements of Java’s module system. These are the features about which every Java programmer
should have at least a basic understanding. As you might guess, the module system provides additional features that give you fine-grained control over the creation and use of modules. For example, both javac and java have many more options related to modules than described in this chapter. Because modules are both a new and significant addition to Java, it is likely that the module system will evolve over time. You will want to watch for enhancements to this innovative aspect of Java.

In conclusion, modules are expected to play an important role in Java programming. Although their use is not required at this time, they offer important benefits for commercial applications that no Java programmer can afford to ignore. It is likely that module-based development will be in every Java programmer’s future.
PART
II The Java Library

CHAPTER 17
String Handling

CHAPTER 18
Exploring java.lang

CHAPTER 19
java.util Part 1:
The Collections Framework

CHAPTER 20
java.util Part 2:
More Utility Classes

CHAPTER 21
Input/Output:
Exploring java.io

CHAPTER 22
Exploring NIO

CHAPTER 23
Networking

CHAPTER 24
Event Handling

CHAPTER 25
Introducing the AWT:
Working with Windows,
Graphics, and Text

CHAPTER 26
Using AWT Controls, Layout
Managers, and Menus
CHAPTER 27
Images

CHAPTER 28
The Concurrency Utilities

CHAPTER 29
The Stream API

CHAPTER 30
Regular Expressions and Other Packages
CHAPTER
17 String Handling

A brief overview of Java’s string handling was presented in Chapter 7. In this chapter, it is described in detail. As is the case in most other programming languages, in Java a string is a sequence of characters. But, unlike some other languages that implement strings as character arrays, Java implements strings as objects of type `String`.

Implementing strings as built-in objects allows Java to provide a full complement of features that make string handling convenient. For example, Java has methods to compare two strings, search for a substring, concatenate two strings, and change the case of letters within a string. Also, `String` objects can be constructed a number of ways, making it easy to obtain a string when needed.

Somewhat unexpectedly, when you create a `String` object, you are creating a string that cannot be changed. That is, once a `String` object has been created, you cannot change the characters that comprise that string. At first, this may seem to be a serious restriction. However, such is not the case. You can still perform all types of string operations. The difference is that each time you need an altered version of an existing string, a new `String` object is created that contains the modifications. The original string is left unchanged. This approach is used because fixed, immutable strings can be implemented more efficiently than changeable ones. For those cases in which a modifiable string is desired, Java provides two options: `StringBuffer` and `StringBuilder`. Both hold strings that can be modified after they are created.

The `String`, `StringBuffer`, and `StringBuilder` classes are defined in `java.lang`. Thus, they are available to all programs automatically. All are declared `final`, which means that none of these classes may be subclassed. This allows certain optimizations that increase performance to take place on common string operations. All three implement the `CharSequence` interface.

One last point: To say that the strings within objects of type `String` are unchangeable means that the contents of the `String` instance cannot be changed after it has been created. However, a variable declared as a `String` reference can be changed to point at some other `String` object at any time.

The String Constructors

The `String` class supports several constructors. To create an empty `String`, call the
default constructor. For example,

```java
String s = new String();
```

will create an instance of `String` with no characters in it.

Frequently, you will want to create strings that have initial values. The `String` class provides a variety of constructors to handle this. To create a `String` initialized by an array of characters, use the constructor shown here:

```java
String(char chars[])  
```

Here is an example:

```java
char chars[] = { 'a', 'b', 'c' };  
String s = new String(chars);  
```

This constructor initializes `s` with the string "abc".

You can specify a subrange of a character array as an initializer using the following constructor:

```java
String(char chars[], int startIndex, int numChars)  
```

Here, `startIndex` specifies the index at which the subrange begins, and `numChars` specifies the number of characters to use. Here is an example:

```java
char chars[] = { 'a', 'b', 'c', 'd', 'e', 'f' };  
String s = new String(chars, 2, 3);  
```

This initializes `s` with the characters cde.

You can construct a `String` object that contains the same character sequence as another `String` object using this constructor:

```java
String(String strObj)  
```

Here, `strObj` is a `String` object. Consider this example:

```java
// Construct one String from another.  
class MakeString {  
   public static void main(String args[]) {  
      char c[] = {'J', 'a', 'v', 'a'};  
      String s1 = new String(c);  
      String s2 = new String(s1);  
      System.out.println(s1);  
      System.out.println(s2);  
   }  
}
```
The output from this program is as follows:

Java
Java

As you can see, \texttt{s1} and \texttt{s2} contain the same string.

Even though Java’s \texttt{char} type uses 16 bits to represent the basic Unicode character set, the typical format for strings on the Internet uses arrays of 8-bit bytes constructed from the ASCII character set. Because 8-bit ASCII strings are common, the \texttt{String} class provides constructors that initialize a string when given a \texttt{byte} array. Two forms are shown here:

\begin{verbatim}
String(byte chrs[ ])
String(byte chrs[ ], int startIndex, int numChars)
\end{verbatim}

Here, \texttt{chrs} specifies the array of bytes. The second form allows you to specify a subrange. In each of these constructors, the byte-to-character conversion is done by using the default character encoding of the platform. The following program illustrates these constructors:

\begin{verbatim}
// Construct string from subset of char array.
class SubStringCons {
    public static void main(String args[]) {
        byte ascii[] = {65, 66, 67, 68, 69, 70 };

        String s1 = new String(ascii);
        System.out.println(s1);

        String s2 = new String(ascii, 2, 3);
        System.out.println(s2);
    }
}
\end{verbatim}

This program generates the following output:

ABCDEF
CDE

Extended versions of the byte-to-string constructors are also defined in which you can specify the character encoding that determines how bytes are converted to characters. However, you will often want to use the default encoding provided by the platform.

\textbf{NOTE} The contents of the array are copied whenever you create a \texttt{String} object from an array. If you modify the contents of the array after you have created the
string, the **String** will be unchanged.

You can construct a **String** from a **StringBuffer** by using the constructor shown here:

```java
String(StringBuffer strBufObj)
```

You can construct a **String** from a **StringBuilder** by using this constructor:

```java
String(StringBuilder strBuildObj)
```

The following constructor supports the extended Unicode character set:

```java
String(int codePoints[ ], int startIndex, int numChars)
```

Here, `codePoints` is an array that contains Unicode code points. The resulting string is constructed from the range that begins at `startIndex` and runs for `numChars`.

There are also constructors that let you specify a **Charset**.

---

**NOTE**  A discussion of Unicode code points and how they are handled by Java is found in Chapter 18.

---

**String Length**

The length of a string is the number of characters that it contains. To obtain this value, call the `length()` method, shown here:

```java
int length()
```

The following fragment prints "3", since there are three characters in the string `s`:

```java
char chars[] = { 'a', 'b', 'c' };
String s = new String(chars);
System.out.println(s.length());
```

**Special String Operations**

Because strings are a common and important part of programming, Java has added special support for several string operations within the syntax of the language. These operations include the automatic creation of new **String** instances from string literals, concatenation of multiple **String** objects by use of the `+` operator, and the conversion of other data types to a string representation. There are explicit methods available to perform all of these functions, but Java does them automatically as a convenience for the programmer and to add clarity.

**String Literals**
The earlier examples showed how to explicitly create a `String` instance from an array of characters by using the `new` operator. However, there is an easier way to do this using a string literal. For each string literal in your program, Java automatically constructs a `String` object. Thus, you can use a string literal to initialize a `String` object. For example, the following code fragment creates two equivalent strings:

```java
char chars[] = { 'a', 'b', 'c' };
String s1 = new String(chars);
String s2 = "abc"; // use string literal
```

Because a `String` object is created for every string literal, you can use a string literal any place you can use a `String` object. For example, you can call methods directly on a quoted string as if it were an object reference, as the following statement shows. It calls the `length()` method on the string "abc". As expected, it prints "3".

```java
System.out.println("abc".length());
```

### String Concatenation

In general, Java does not allow operators to be applied to `String` objects. The one exception to this rule is the `+` operator, which concatenates two strings, producing a `String` object as the result. This allows you to chain together a series of `+` operations. For example, the following fragment concatenates three strings:

```java
String age = "9";
String s = "He is " + age + " years old."
System.out.println(s);
```

This displays the string "He is 9 years old."

One practical use of string concatenation is found when you are creating very long strings. Instead of letting long strings wrap around within your source code, you can break them into smaller pieces, using the `+` to concatenate them. Here is an example:
String Concatenation with Other Data Types

You can concatenate strings with other types of data. For example, consider this slightly different version of the earlier example:

```java
int age = 9;
String s = "He is " + age + " years old.";
System.out.println(s);
```

In this case, `age` is an `int` rather than another `String`, but the output produced is the same as before. This is because the `int` value in `age` is automatically converted into its string representation within a `String` object. This string is then concatenated as before. The compiler will convert an operand to its string equivalent whenever the other operand of the `+` is an instance of `String`.

Be careful when you mix other types of operations with string concatenation expressions, however. You might get surprising results. Consider the following:

```java
String s = "four: " + 2 + 2;
System.out.println(s);
```

This fragment displays

```
four: 22
```

rather than the

```
four: 4
```

that you probably expected. Here’s why. Operator precedence causes the concatenation of "four" with the string equivalent of 2 to take place first. This result is then concatenated with the string equivalent of 2 a second time. To complete the integer addition first, you must use parentheses, like this:
Now s contains the string "four: 4".

**String Conversion and toString()**

When Java converts data into its string representation during concatenation, it does so by calling one of the overloaded versions of the string conversion method `valueOf()` defined by `String`. `valueOf()` is overloaded for all the primitive types and for type `Object`. For the primitive types, `valueOf()` returns a string that contains the human-readable equivalent of the value with which it is called. For objects, `valueOf()` calls the `toString()` method on the object. We will look more closely at `valueOf()` later in this chapter. Here, let’s examine the `toString()` method, because it is the means by which you can determine the string representation for objects of classes that you create.

Every class implements `toString()` because it is defined by `Object`. However, the default implementation of `toString()` is seldom sufficient. For most important classes that you create, you will want to override `toString()` and provide your own string representations. Fortunately, this is easy to do. The `toString()` method has this general form:

```java
String toString()
```

To implement `toString()`, simply return a `String` object that contains the human-readable string that appropriately describes an object of your class.

By overriding `toString()` for classes that you create, you allow them to be fully integrated into Java’s programming environment. For example, they can be used in `print()` and `println()` statements and in concatenation expressions. The following program demonstrates this by overriding `toString()` for the `Box` class:
// Override toString() for Box class.
class Box {
    double width;
    double height;
    double depth;

    Box(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }

    public String toString() {
        return "Dimensions are " + width + " by " +
                depth + " by " + height + ".";
    }
}

class toStringDemo {
    public static void main(String args[]) {
        Box b = new Box(10, 12, 14);
        String s = "Box b: " + b; // concatenate Box object

        System.out.println(b); // convert Box to string
        System.out.println(s);
    }
}

The output of this program is shown here:

Dimensions are 10.0 by 14.0 by 12.0
Box b: Dimensions are 10.0 by 14.0 by 12.0

As you can see, Box’s toString() method is automatically invoked when a Box object is used in a concatenation expression or in a call to println().

**Character Extraction**

The String class provides a number of ways in which characters can be extracted from a String object. Several are examined here. Although the characters that comprise a string within a String object cannot be indexed as if they were a character array, many of the String methods employ an index (or offset) into the string for their operation. Like arrays, the string indexes begin at zero.
**charAt()**

To extract a single character from a String, you can refer directly to an individual character via the `charAt()` method. It has this general form:

```java
char charAt(int where)
```

Here, `where` is the index of the character that you want to obtain. The value of `where` must be nonnegative and specify a location within the string. `charAt()` returns the character at the specified location. For example,

```java
c char ch;
c ch = "abc".charAt(1);
```

assigns the value b to ch.

**getChars()**

If you need to extract more than one character at a time, you can use the `getChars()` method. It has this general form:

```java
void getChars(int sourceStart, int sourceEnd, char target[ ], int targetStart)
```

Here, `sourceStart` specifies the index of the beginning of the substring, and `sourceEnd` specifies an index that is one past the end of the desired substring. Thus, the substring contains the characters from `sourceStart` through `sourceEnd`–1. The array that will receive the characters is specified by `target`. The index within `target` at which the substring will be copied is passed in `targetStart`. Care must be taken to assure that the `target` array is large enough to hold the number of characters in the specified substring.

The following program demonstrates `getChars()`:

```java
class getCharsDemo {
c public static void main(String args[]) {
c String s = "This is a demo of the getChars method.";
c int start = 10;
c int end = 14;
c char buf[] = new char[end - start];

c s.getChars(start, end, buf, 0);
c System.out.println(buf);
}
}
```

Here is the output of this program:
getBytes() 
There is an alternative to getChars() that stores the characters in an array of bytes. This method is called getBytes(), and it uses the default character-to-byte conversions provided by the platform. Here is its simplest form:
```java
byte[ ] getBytes()
```
Other forms of getBytes() are also available. getBytes() is most useful when you are exporting a String value into an environment that does not support 16-bit Unicode characters. For example, most Internet protocols and text file formats use 8-bit ASCII for all text interchange.

toCharArray() 
If you want to convert all the characters in a String object into a character array, the easiest way is to call toCharArray(). It returns an array of characters for the entire string. It has this general form:
```java
char[ ] toCharArray()
```
This function is provided as a convenience, since it is possible to use getChars() to achieve the same result.

String Comparison
The String class includes a number of methods that compare strings or substrings within strings. Several are examined here.

equals() and equalsIgnoreCase() 
To compare two strings for equality, use equals(). It has this general form:
```java
boolean equals(Object str)
```
Here, str is the String object being compared with the invoking String object. It returns true if the strings contain the same characters in the same order, and false otherwise. The comparison is case-sensitive.
To perform a comparison that ignores case differences, call equalsIgnoreCase(). When it compares two strings, it considers A-Z to be the same as a-z. It has this general form:
```java
boolean equalsIgnoreCase(String str)
```
Here, str is the String object being compared with the invoking String object. It,
too, returns true if the strings contain the same characters in the same order, and false otherwise.

Here is an example that demonstrates equals() and equalsIgnoreCase():

```java
// Demonstrate equals() and equalsIgnoreCase().
class equalsDemo {
    public static void main(String args[]) {
        String s1 = "Hello";
        String s2 = "Hello";
        String s3 = "Good-bye";
        String s4 = "HELLO";
        System.out.println(s1 + " equals " + s2 + " -> " +
                           s1.equals(s2));
        System.out.println(s1 + " equals " + s3 + " -> " +
                           s1.equals(s3));
        System.out.println(s1 + " equals " + s4 + " -> " +
                           s1.equals(s4));
        System.out.println(s1 + " equalsIgnoreCase " + s4 + " -> " +
                           s1.equalsIgnoreCase(s4));
    }
}
```

The output from the program is shown here:

Hello equals Hello -> true
Hello equals Good-bye -> false
Hello equals HELLO -> false
Hello equalsIgnoreCase HELLO -> true

regionMatches()

The regionMatches() method compares a specific region inside a string with another specific region in another string. There is an overloaded form that allows you to ignore case in such comparisons. Here are the general forms for these two methods:

```
boolean regionMatches(int startIndex, String str2,
                      int str2StartIndex, int numChars)

boolean regionMatches(boolean ignoreCase,
                      int startIndex, String str2,
                      int str2StartIndex, int numChars)
```
For both versions, startIndex specifies the index at which the region begins within the invoking String object. The String being compared is specified by str2. The index at which the comparison will start within str2 is specified by str2StartIndex. The length of the substring being compared is passed in numChars. In the second version, if ignoreCase is true, the case of the characters is ignored. Otherwise, case is significant.

startsWith( ) and endsWith( )

String defines two methods that are, more or less, specialized forms of regionMatches( ). The startsWith( ) method determines whether a given String begins with a specified string. Conversely, endsWith( ) determines whether the String in question ends with a specified string. They have the following general forms:

    boolean startsWith(String str)
    boolean endsWith(String str)

Here, str is the String being tested. If the string matches, true is returned. Otherwise, false is returned. For example,

"Foobar".endsWith("bar")

and

"Foobar".startsWith("Foo")

are both true.

A second form of startsWith( ), shown here, lets you specify a starting point:

    boolean startsWith(String str, int startIndex)

Here, startIndex specifies the index into the invoking string at which point the search will begin. For example,

"Foobar".startsWith("bar", 3)

returns true.

equals( ) Versus ==

It is important to understand that the equals( ) method and the == operator perform two different operations. As just explained, the equals( ) method compares the characters inside a String object. The == operator compares two object references to see whether they refer to the same instance. The following program shows how two
different String objects can contain the same characters, but references to these objects will not compare as equal:

```java
// equals() vs ==
class EqualsNotEqualTo {
    public static void main(String args[]) {

        String s1 = "Hello";
        String s2 = new String(s1);

        System.out.println(s1 + " equals " + s2 + " -> " +
                           s1.equals(s2));
        System.out.println(s1 + " == " + s2 + " -> " + (s1 == s2));
    }
}
```

The variable s1 refers to the String instance created by "Hello". The object referred to by s2 is created with s1 as an initializer. Thus, the contents of the two String objects are identical, but they are distinct objects. This means that s1 and s2 do not refer to the same objects and are, therefore, not ==, as is shown here by the output of the preceding example:

```
Hello equals Hello -> true
Hello == Hello -> false
```

**compareTo()**

Often, it is not enough to simply know whether two strings are identical. For sorting applications, you need to know which is less than, equal to, or greater than the next. A string is less than another if it comes before the other in dictionary order. A string is greater than another if it comes after the other in dictionary order. The method compareTo() serves this purpose. It is specified by the Comparable<T> interface, which String implements. It has this general form:

```java
int compareTo(String str)
```

Here, str is the String being compared with the invoking String. The result of the comparison is returned and is interpreted as shown here:
Here is a sample program that sorts an array of strings. The program uses `compareTo()` to determine sort ordering for a bubble sort:

```java
// A bubble sort for Strings.
class SortString {
    static String arr[] = {
        "Now", "is", "the", "time", "for", "all", "good", "men", "to", "come", "to", "the", "aid", "of", "their", "country"
    };
    public static void main(String args[]) {
        for(int j = 0; j < arr.length; j++) {
            for(int i = j + 1; i < arr.length; i++) {
                if(arr[i].compareTo(arr[j]) < 0) {
                    String t = arr[j];
                    arr[j] = arr[i];
                    arr[i] = t;
                }
            }
        }
        System.out.println(arr[j]);
    }
}
```

The output of this program is the list of words:
As you can see from the output of this example, `compareTo()` takes into account uppercase and lowercase letters. The word "Now" came out before all the others because it begins with an uppercase letter, which means it has a lower value in the ASCII character set.

If you want to ignore case differences when comparing two strings, use `compareToIgnoreCase()`, as shown here:

```java
int compareToIgnoreCase(String str)
```

This method returns the same results as `compareTo()`, except that case differences are ignored. You might want to try substituting it into the previous program. After doing so, "Now" will no longer be first.

**Searching Strings**

The `String` class provides two methods that allow you to search a string for a specified character or substring:

- `indexOf()` Searches for the first occurrence of a character or substring.
- `lastIndexOf()` Searches for the last occurrence of a character or substring.

These two methods are overloaded in several different ways. In all cases, the methods return the index at which the character or substring was found, or –1 on failure.

To search for the first occurrence of a character, use

```java
int indexOf(int ch)
```

To search for the last occurrence of a character, use
int lastIndexOf(int ch)

Here, ch is the character being sought.
To search for the first or last occurrence of a substring, use
int indexOf(String str)
int lastIndexOf(String str)

Here, str specifies the substring.
You can specify a starting point for the search using these forms:

int indexOf(int ch, int startIndex)
int lastIndexOf(int ch, int startIndex)

int indexOf(String str, int startIndex)
int lastIndexOf(String str, int startIndex)

Here, startIndex specifies the index at which point the search begins. For indexOf( ), the search runs from startIndex to the end of the string. For lastIndexOf( ), the search runs from startIndex to zero.
The following example shows how to use the various index methods to search inside of a String:
Here is the output of this program:

Now is the time for all good men to come to the aid of their country.
indexOf(t) = 7
lastIndexOf(t) = 65
indexOf(the) = 7
lastIndexOf(the) = 55
indexOf(t, 10) = 11
lastIndexOf(t, 60) = 55
indexOf(the, 10) = 44
lastIndexOf(the, 60) = 55

Modifying a String

Because String objects are immutable, whenever you want to modify a String, you must either copy it into a StringBuffer or StringBuilder, or use a String method that constructs a new copy of the string with your modifications complete. A sampling of these methods are described here.
You can extract a substring using `substring()`. It has two forms. The first is

```
String substring(int startIndex)
```

Here, `startIndex` specifies the index at which the substring will begin. This form returns a copy of the substring that begins at `startIndex` and runs to the end of the invoking string.

The second form of `substring()` allows you to specify both the beginning and ending index of the substring:

```
String substring(int startIndex, int endIndex)
```

Here, `startIndex` specifies the beginning index, and `endIndex` specifies the stopping point. The string returned contains all the characters from the beginning index, up to, but not including, the ending index.

The following program uses `substring()` to replace all instances of one substring with another within a string:

```java
// Substring replacement.
class StringReplace {
    public static void main(String args[]) {
        String org = "This is a test. This is, too.";
        String search = "is";
        String sub = "was";
        String result = "";
        int i;

        do { // replace all matching substrings
            System.out.println(org);
            i = org.indexOf(search);

            if(i != -1) {
                result = org.substring(0, i);
                result = result + sub;
                result = result + org.substring(i + search.length());
                org = result;
            }
        } while(i != -1);
    }
}
```

The output from this program is shown here:
concat( )
You can concatenate two strings using concat( ), shown here:

String concat(String str)
This method creates a new object that contains the invoking string with the contents of str appended to the end. concat( ) performs the same function as +. For example,

String s1 = "one";
String s2 = s1.concat("two");

puts the string "onetwo" into s2. It generates the same result as the following sequence:

String s1 = "one";
String s2 = s1 + "two";

replace( )
The replace( ) method has two forms. The first replaces all occurrences of one character in the invoking string with another character. It has the following general form:

String replace(char original, char replacement)
Here, original specifies the character to be replaced by the character specified by replacement. The resulting string is returned. For example,

String s = "Hello".replace('l', 'w');

puts the string "Hewwo" into s.
The second form of replace( ) replaces one character sequence with another. It has this general form:

String replace(CharSequence original, CharSequence replacement)
trim( )
The trim( ) method returns a copy of the invoking string from which any leading and
trailing whitespace has been removed. It has this general form:

    String trim()

Here is an example:

    String s = "   Hello World   ".trim();

This puts the string "Hello World" into s.

The trim() method is quite useful when you process user commands. For example, the following program prompts the user for the name of a state and then displays that state's capital. It uses trim() to remove any leading or trailing whitespace that may have inadvertently been entered by the user.

    // Using trim() to process commands.
    import java.io.*;

    class UseTrim {
        public static void main(String args[])
            throws IOException
        {
            // create a BufferedReader using System.in
            BufferedReader br = new
            BufferedReader(new InputStreamReader(System.in));
            String str;

            System.out.println("Enter 'stop' to quit.");
            System.out.println("Enter State: ");
            do {
                str = br.readLine();
                str = str.trim(); // remove whitespace

                if(str.equals("Illinois"))
                    System.out.println("Capital is Springfield.");
                else if(str.equals("Missouri"))
                    System.out.println("Capital is Jefferson City.");
                else if(str.equals("California"))
                    System.out.println("Capital is Sacramento.");
                else if(str.equals("Washington"))
                    System.out.println("Capital is Olympia.");
                    // ...
            } while(!str.equals("stop"));
        }
    }
Data Conversion Using valueOf( )

The `valueOf()` method converts data from its internal format into a human-readable form. It is a static method that is overloaded within `String` for all of Java’s built-in types so that each type can be converted properly into a string. `valueOf()` is also overloaded for type `Object`, so an object of any class type you create can also be used as an argument. (Recall that `Object` is a superclass for all classes.) Here are a few of its forms:

```java
static String valueOf(double num)
static String valueOf(long num)
static String valueOf(Object ob)
static String valueOf(char chars[])
```

As discussed earlier, `valueOf()` is called when a string representation of some other type of data is needed—for example, during concatenation operations. You can call this method directly with any data type and get a reasonable `String` representation. All of the simple types are converted to their common `String` representation. Any object that you pass to `valueOf()` will return the result of a call to the object’s `toString()` method. In fact, you could just call `toString()` directly and get the same result.

For most arrays, `valueOf()` returns a rather cryptic string, which indicates that it is an array of some type. For arrays of `char`, however, a `String` object is created that contains the characters in the `char` array. There is a special version of `valueOf()` that allows you to specify a subset of a `char` array. It has this general form:

```java
static String valueOf(char chars[], int startIndex, int numChars)
```

Here, `chars` is the array that holds the characters, `startIndex` is the index into the array of characters at which the desired substring begins, and `numChars` specifies the length of the substring.

Changing the Case of Characters Within a String

The method `toLowerCase()` converts all the characters in a string from uppercase to lowercase. The `toUpperCase()` method converts all the characters in a string from lowercase to uppercase. Nonalphabetical characters, such as digits, are unaffected. Here are the simplest forms of these methods:

```java
String toLowerCase()
```
String toUpperCase( )

Both methods return a String object that contains the uppercase or lowercase equivalent of the invoking String. The default locale governs the conversion in both cases.

Here is an example that uses toLowerCase( ) and toUpperCase( ):

```java
// Demonstrate toUpperCase() and toLowerCase().

class ChangeCase {
    public static void main(String args[])
    {
        String s = "This is a test."
        System.out.println("Original: " + s);

        String upper = s.toUpperCase();
        String lower = s.toLowerCase();
        System.out.println("Uppercase: " + upper);
        System.out.println("Lowercase: " + lower);
    }
}
```

The output produced by the program is shown here:

```
Original: This is a test.
Uppercase: THIS IS A TEST.
Lowercase: this is a test.
```

One other point: Overloaded versions of toLowerCase( ) and toUpperCase( ) that let you specify a Locale object to govern the conversion are also supplied. Specifying the locale can be quite important in some cases and can help internationalize your application.

**Joining Strings**

JDK 8 added a new method to String called join( ). It is used to concatenate two or more strings, separating each string with a delimiter, such as a space or a comma. It has two forms. Its first is shown here:

```
static String join(CharSequence delim, CharSequence … strs)
```

Here, delim specifies the delimiter used to separate the character sequences specified by strs. Because String implements the CharSequence interface, strs can be a list of
strings. (See Chapter 18 for information on `CharSequence`.) The following program demonstrates this version of `join()`:

```java
// Demonstrate the join() method defined by String.
class StringJoinDemo {
    public static void main(String args[]) {

        String result = String.join(" ", "Alpha", "Beta", "Gamma");
        System.out.println(result);

        result = String.join(" ", "John", "ID#: 569",
                     "E-mail: John@HerbSchildt.com");
        System.out.println(result);
    }
}
```

The output is shown here:

```
Alpha Beta Gamma
John, ID#: 569, E-mail: John@HerbSchildt.com
```

In the first call to `join()`, a space is inserted between each string. In the second call, the delimiter is a comma followed by a space. This illustrates that the delimiter need not be just a single character.

The second form of `join()` lets you join a list of strings obtained from an object that implements the `Iterable` interface. `Iterable` is implemented by the Collections Framework classes described in Chapter 19, among others. See Chapter 18 for information on `Iterable`.

**Additional String Methods**

In addition to those methods discussed earlier, `String` has many other methods. Several are summarized in the following table:
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>int codePointAt(int i)</td>
<td>Returns the Unicode code point at the location specified by i.</td>
</tr>
<tr>
<td>int codePointBefore(int i)</td>
<td>Returns the Unicode code point at the location that precedes that specified by i.</td>
</tr>
<tr>
<td>int codePointCount(int start, int end)</td>
<td>Returns the number of code points in the portion of the invoking String that are between start and end–1.</td>
</tr>
<tr>
<td>boolean contains(CharSequence str)</td>
<td>Returns true if the invoking object contains the string specified by str. Returns false otherwise.</td>
</tr>
<tr>
<td>boolean contentEquals(CharSequence str)</td>
<td>Returns true if the invoking string contains the same string as str. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean contentEquals(StringBuffer str)</td>
<td>Returns true if the invoking string contains the same string as str. Otherwise, returns false.</td>
</tr>
<tr>
<td>static String format(String fmtstr, Object ... args)</td>
<td>Returns a string formatted as specified by fmtstr. (See Chapter 19 for details on formatting.)</td>
</tr>
<tr>
<td>static String format(Locale loc, String fmtstr, Object ... args)</td>
<td>Returns a string formatted as specified by fmtstr. Formatting is governed by the locale specified by loc. (See Chapter 19 for details on formatting.)</td>
</tr>
<tr>
<td>boolean isEmpty()</td>
<td>Returns true if the invoking string contains no characters and has a length of zero.</td>
</tr>
<tr>
<td>boolean matches(String regExp)</td>
<td>Returns true if the invoking string matches the regular expression passed in regExp. Otherwise, returns false.</td>
</tr>
<tr>
<td>int offsetByCodePoints(int start, int num)</td>
<td>Returns the index within the invoking string that is num code points beyond the starting index specified by start.</td>
</tr>
<tr>
<td>String replaceFirst(String regExp, String newStr)</td>
<td>Returns a string in which the first substring that matches the regular expression specified by regExp is replaced by newStr.</td>
</tr>
<tr>
<td>String replaceAll(String regExp, String newStr)</td>
<td>Returns a string in which all substrings that match the regular expression specified by regExp are replaced by newStr.</td>
</tr>
<tr>
<td>String[] split(String regExp)</td>
<td>Decomposes the invoking string into parts and returns an array that contains the result. Each part is delimited by the regular expression passed in regExp.</td>
</tr>
</tbody>
</table>
Notice that several of these methods work with regular expressions. Regular expressions are described in Chapter 30.

### StringBuffer

StringBuffer supports a modifiable string. As you know, String represents fixed-length, immutable character sequences. In contrast, StringBuffer represents growable and writable character sequences. StringBuffer may have characters and substrings inserted in the middle or appended to the end. StringBuffer will automatically grow to make room for such additions and often has more characters preallocated than are actually needed, to allow room for growth.

### StringBuffer Constructors

StringBuffer defines these four constructors:

- `StringBuffer( )`
- `StringBuffer(int size)`
- `StringBuffer(String str)`
- `StringBuffer(CharSequence chars)`

The default constructor (the one with no parameters) reserves room for 16 characters without reallocation. The second version accepts an integer argument that explicitly sets the size of the buffer. The third version accepts a String argument that sets the initial contents of the StringBuffer object and reserves room for 16 more characters without reallocation. StringBuffer allocates room for 16 additional
characters when no specific buffer length is requested, because reallocation is a costly process in terms of time. Also, frequent reallocations can fragment memory. By allocating room for a few extra characters, StringBuffer reduces the number of reallocations that take place. The fourth constructor creates an object that contains the character sequence contained in chars and reserves room for 16 more characters.

**length( ) and capacity( )**

The current length of a StringBuffer can be found via the length( ) method, while the total allocated capacity can be found through the capacity( ) method. They have the following general forms:

```java
int length()
int capacity()
```

Here is an example:

```java
// StringBuffer length vs. capacity.
class StringBufferDemo {
    public static void main(String args[]) {
        StringBuffer sb = new StringBuffer("Hello");

        System.out.println("buffer = " + sb);
        System.out.println("length = " + sb.length());
        System.out.println("capacity = " + sb.capacity());
    }
}
```

Here is the output of this program, which shows how StringBuffer reserves extra space for additional manipulations:

```
buffer = Hello
length = 5
capacity = 21
```

Since sb is initialized with the string "Hello" when it is created, its length is 5. Its capacity is 21 because room for 16 additional characters is automatically added.

**ensureCapacity( )**

If you want to preallocate room for a certain number of characters after a StringBuffer has been constructed, you can use ensureCapacity( ) to set the size of the buffer. This is useful if you know in advance that you will be appending a large
number of small strings to a StringBuffer. **ensureCapacity( )** has this general form:

```java
define void ensureCapacity(int minCapacity)
```

Here, *minCapacity* specifies the minimum size of the buffer. (A buffer larger than *minCapacity* may be allocated for reasons of efficiency.)

**setLength( )**

To set the length of the string within a StringBuffer object, use **setLength( )**. Its general form is shown here:

```java
define void setLength(int len)
```

Here, *len* specifies the length of the string. This value must be nonnegative.

When you increase the size of the string, null characters are added to the end. If you call **setLength( )** with a value less than the current value returned by **length( )**, then the characters stored beyond the new length will be lost. The **setCharAtDemo** sample program in the following section uses **setLength( )** to shorten a StringBuffer.

**charAt( ) and setCharAt( )**

The value of a single character can be obtained from a StringBuffer via the **charAt( )** method. You can set the value of a character within a StringBuffer using **setCharAt( )**. Their general forms are shown here:

```java
char charAt(int where)

define void setCharAt(int where, char ch)
```

For **charAt( )**, *where* specifies the index of the character being obtained. For **setCharAt( )**, *where* specifies the index of the character being set, and *ch* specifies the new value of that character. For both methods, *where* must be nonnegative and must not specify a location beyond the end of the string.

The following example demonstrates **charAt( )** and **setCharAt( )**:
// Demonstrate charAt() and setCharAt().
class setCharAtDemo {
    public static void main(String args[]) {
        StringBuffer sb = new StringBuffer("Hello");
        System.out.println("buffer before = " + sb);
        System.out.println("charAt(1) before = " + sb.charAt(1));

        sb.setCharAt(1, 'i');
        sb.setLength(2);
        System.out.println("buffer after = " + sb);
        System.out.println("charAt(1) after = " + sb.charAt(1));
    }
}

Here is the output generated by this program:

buffer before = Hello
charAt(1) before = e
buffer after = Hi
charAt(1) after = i

getChars()  
To copy a substring of a StringBuffer into an array, use the getChars() method. It has this general form:

    void getChars(int sourceStart, int sourceEnd, char target[], int targetStart)

Here, sourceStart specifies the index of the beginning of the substring, and sourceEnd specifies an index that is one past the end of the desired substring. This means that the substring contains the characters from sourceStart through sourceEnd–1. The array that will receive the characters is specified by target. The index within target at which the substring will be copied is passed in targetStart. Care must be taken to assure that the target array is large enough to hold the number of characters in the specified substring.

append()  
The append() method concatenates the string representation of any other type of data to the end of the invoking StringBuffer object. It has several overloaded versions. Here are a few of its forms:

    StringBuffer append(String str)
    StringBuffer append(int num)
StringBuffer append(Object obj)

The string representation of each parameter is obtained, often by calling `String.valueOf()`. The result is appended to the current `StringBuffer` object. The buffer itself is returned by each version of `append()`. This allows subsequent calls to be chained together, as shown in the following example:

```java
// Demonstrate append().
class appendDemo {
    public static void main(String args[]) {
        String s;
        int a = 42;
        StringBuffer sb = new StringBuffer(40);

        s = sb.append("a = ").append(a).append("!").toString();
        System.out.println(s);
    }
}
```

The output of this example is shown here:

```
a = 42!
```

**insert( )**

The `insert( )` method inserts one string into another. It is overloaded to accept values of all the primitive types, plus `Strings`, `Objects`, and `CharSequences`. Like `append()`, it obtains the string representation of the value it is called with. This string is then inserted into the invoking `StringBuffer` object. These are a few of its forms:

```java
StringBuffer insert(int index, String str)
StringBuffer insert(int index, char ch)
StringBuffer insert(int index, Object obj)
```

Here, `index` specifies the index at which point the string will be inserted into the invoking `StringBuffer` object.

The following sample program inserts "like" between "I" and "Java":

```java
```
reverse( )

You can reverse the characters within a StringBuffer object using reverse( ), shown here:

```
StringBuffer reverse( )
```

This method returns the reverse of the object on which it was called. The following program demonstrates reverse( ):

```java
// Using reverse() to reverse a StringBuffer.
class ReverseDemo {
    public static void main(String args[]) {
        StringBuffer s = new StringBuffer("abcdef");

        System.out.println(s);
        s.reverse();
        System.out.println(s);
    }
}
```

Here is the output produced by the program:

```
abcdef
fedcba
```

delete( ) and deleteCharAt( )

You can delete characters within a StringBuffer by using the methods delete( ) and deleteCharAt( ). These methods are shown here:

```
StringBuffer delete(int startIndex, int endIndex)
StringBuffer deleteCharAt(int loc)
```
The \texttt{delete()} method deletes a sequence of characters from the invoking object. Here, \texttt{startIndex} specifies the index of the first character to remove, and \texttt{endIndex} specifies an index one past the last character to remove. Thus, the substring deleted runs from \texttt{startIndex} to \texttt{endIndex} – 1. The resulting \texttt{StringBuffer} object is returned.

The \texttt{deleteCharAt()} method deletes the character at the index specified by \texttt{loc}. It returns the resulting \texttt{StringBuffer} object.

Here is a program that demonstrates the \texttt{delete()} and \texttt{deleteCharAt()} methods:

```java
// Demonstrate delete() and deleteCharAt()
class deleteDemo {
    public static void main(String args[]) {
        StringBuffer sb = new StringBuffer("This is a test.");
        sb.delete(4, 7);
        System.out.println("After delete: " + sb);

        sb.deleteCharAt(0);
        System.out.println("After deleteCharAt: " + sb);
    }
}
```

The following output is produced:

```
After delete: This is a test.
After deleteCharAt: his a test.
```

\textbf{replace( )}

You can replace one set of characters with another set inside a \texttt{StringBuffer} object by calling \texttt{replace( )}. Its signature is shown here:

\texttt{StringBuffer replace(int startIndex, int endIndex, String str)}

The substring being replaced is specified by the indexes \texttt{startIndex} and \texttt{endIndex}. Thus, the substring at \texttt{startIndex} through \texttt{endIndex} – 1 is replaced. The replacement string is passed in \texttt{str}. The resulting \texttt{StringBuffer} object is returned.

The following program demonstrates \texttt{replace( )}:
// Demonstrate replace()
class replaceDemo {
    public static void main(String args[]) {
        StringBuffer sb = new StringBuffer("This is a test.");

        sb.replace(5, 7, "was");
        System.out.println("After replace: " + sb);
    }
}

Here is the output:

    After replace: This was a test.

**substring()**

You can obtain a portion of a `StringBuffer` by calling `substring()`. It has the following two forms:

    String substring(int startIndex)
    String substring(int startIndex, int endIndex)

The first form returns the substring that starts at `startIndex` and runs to the end of the invoking `StringBuffer` object. The second form returns the substring that starts at `startIndex` and runs through `endIndex`–1. These methods work just like those defined for `String` that were described earlier.

**Additional StringBuffer Methods**

In addition to those methods just described, `StringBuffer` supplies others. Several are summarized in the following table:
### Method Description

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>StringBuffer appendCodePoint(int \textit{ch})</td>
<td>Appends a Unicode code point to the end of the invoking object. A reference to the object is returned.</td>
</tr>
<tr>
<td>int codePointAt(int \textit{i})</td>
<td>Returns the Unicode code point at the location specified by \textit{i}.</td>
</tr>
<tr>
<td>int codePointBefore(int \textit{i})</td>
<td>Returns the Unicode code point at the location that precedes that specified by \textit{i}.</td>
</tr>
<tr>
<td>int codePointCount(int \textit{start}, int \textit{end})</td>
<td>Returns the number of code points in the portion of the invoking \textit{String} that are between \textit{start} and \textit{end}–1.</td>
</tr>
<tr>
<td>int indexOf(String \textit{str})</td>
<td>Searches the invoking StringBuffer for the first occurrence of \textit{str}. Returns the index of the match, or \textit{-1} if no match is found.</td>
</tr>
<tr>
<td>int indexOf(String \textit{str}, int \textit{startInd})</td>
<td>Searches the invoking StringBuffer for the first occurrence of \textit{str}, beginning at \textit{startInd}. Returns the index of the match, or \textit{-1} if no match is found.</td>
</tr>
<tr>
<td>int lastIndexOf(String \textit{str})</td>
<td>Searches the invoking StringBuffer for the last occurrence of \textit{str}. Returns the index of the match, or \textit{-1} if no match is found.</td>
</tr>
<tr>
<td>int lastIndexOf(String \textit{str}, int \textit{startInd})</td>
<td>Searches the invoking StringBuffer for the last occurrence of \textit{str}, beginning at \textit{startInd}. Returns the index of the match, or \textit{-1} if no match is found.</td>
</tr>
<tr>
<td>int offsetByCodePoints(int \textit{start}, int \textit{num})</td>
<td>Returns the index within the invoking string that is \textit{num} code points beyond the starting index specified by \textit{start}.</td>
</tr>
<tr>
<td>CharSequence subSequence(int \textit{startInd}, int \textit{stopInd})</td>
<td>Returns a substring of the invoking string, beginning at \textit{startInd} and stopping at \textit{stopInd}. This method is required by the \textit{CharSequence} interface, which is implemented by \textit{StringBuffer}.</td>
</tr>
<tr>
<td>void trimToSize()</td>
<td>Requests that the size of the character buffer for the invoking object be reduced to better fit the current contents.</td>
</tr>
</tbody>
</table>

The following program demonstrates \texttt{indexOf()} and \texttt{lastIndexOf()}:

```java
String str = "Hello, world!"
int index = str.indexOf("world");
int lastIndex = str.lastIndexOf("world");
```
class IndexOfDemo {
    public static void main(String args[]) {
        StringBuffer sb = new StringBuffer("one two one");
        int i;

        i = sb.indexOf("one");
        System.out.println("First index: " + i);

        i = sb.lastIndexOf("one");
        System.out.println("Last index: " + i);
    }
}

The output is shown here:

First index: 0
Last index: 8

**StringBuilder**

*StringBuilder* is similar to *StringBuffer* except for one important difference: it is not synchronized, which means that it is not thread-safe. The advantage of *StringBuilder* is faster performance. However, in cases in which a mutable string will be accessed by multiple threads, and no external synchronization is employed, you must use *StringBuffer* rather than *StringBuilder*. 
CHAPTER
18 Exploring java.lang

This chapter discusses classes and interfaces defined by java.lang. As you know, java.lang is automatically imported into all programs. It contains classes and interfaces that are fundamental to virtually all of Java programming. It is Java’s most widely used package. Beginning with JDK 9, all of java.lang is part of the java.base module.

java.lang includes the following classes:

<table>
<thead>
<tr>
<th>java.lang</th>
<th>java.lang</th>
<th>java.lang</th>
<th>java.lang</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boolean</td>
<td>Float</td>
<td>Process</td>
<td>StrictMath</td>
</tr>
<tr>
<td>Byte</td>
<td>InheritableThreadLocal</td>
<td>ProcessBuilder</td>
<td>String</td>
</tr>
<tr>
<td>Character</td>
<td>Integer</td>
<td>ProcessBuilder.Redirect</td>
<td>StringBuffer</td>
</tr>
<tr>
<td>Character.Subset</td>
<td>Long</td>
<td>Runtime</td>
<td>StringBuilder</td>
</tr>
<tr>
<td>Character.UnicodeBlock</td>
<td>Math</td>
<td>RuntimePermission</td>
<td>System</td>
</tr>
<tr>
<td>Class</td>
<td>Module</td>
<td>Runtime.Version</td>
<td>System.LoggerFinder</td>
</tr>
<tr>
<td>ClassLoader</td>
<td>ModuleLayer</td>
<td>SecurityManager</td>
<td>Thread</td>
</tr>
<tr>
<td>ClassValue</td>
<td>ModuleLayer.Controller</td>
<td>Short</td>
<td>ThreadGroup</td>
</tr>
<tr>
<td>Compiler</td>
<td>Number</td>
<td>StackFramePermission</td>
<td>ThreadLocal</td>
</tr>
<tr>
<td>Double</td>
<td>Object</td>
<td>StackTraceElement</td>
<td>Throwable</td>
</tr>
<tr>
<td>Enum</td>
<td>Package</td>
<td>StackWalker</td>
<td>Void</td>
</tr>
</tbody>
</table>

java.lang defines the following interfaces:

<table>
<thead>
<tr>
<th>java.lang</th>
<th>java.lang</th>
<th>java.lang</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appendable</td>
<td>Iterable</td>
<td>StackWalker.StackFrame</td>
</tr>
<tr>
<td>AutoCloseable</td>
<td>ProcessHandle</td>
<td>System.Logger</td>
</tr>
<tr>
<td>CharSequence</td>
<td>ProcessHandle.Info</td>
<td>Thread.UncaughtExceptionHandler</td>
</tr>
<tr>
<td>Cloneable</td>
<td>Readable</td>
<td></td>
</tr>
<tr>
<td>Comparable</td>
<td>Runnable</td>
<td></td>
</tr>
</tbody>
</table>

Several of the classes contained in java.lang contain deprecated methods, many dating back to Java 1.0. Deprecated methods are still provided by Java to support
legacy code but are not recommended for new code. Because of this, in most cases the deprecated methods are not discussed here.

**Primitive Type Wrappers**

As mentioned in Part I of this book, Java uses primitive types, such as `int` and `char`, for performance reasons. These data types are not part of the object hierarchy. They are passed by value to methods and cannot be directly passed by reference. Also, there is no way for two methods to refer to the *same instance* of an `int`. At times, you will need to create an object representation for one of these primitive types. For example, there are collection classes discussed in Chapter 19 that deal only with objects; to store a primitive type in one of these classes, you need to wrap the primitive type in a class. To address this need, Java provides classes that correspond to each of the primitive types. In essence, these classes encapsulate, or *wrap*, the primitive types within a class. Thus, they are commonly referred to as *type wrappers*. The type wrappers were introduced in Chapter 12. They are examined in detail here.

**Number**

The abstract class `Number` defines a superclass that is implemented by the classes that wrap the numeric types `byte`, `short`, `int`, `long`, `float`, and `double`. `Number` has abstract methods that return the value of the object in each of the different number formats. For example, `doubleValue( )` returns the value as a `double`, `floatValue( )` returns the value as a `float`, and so on. These methods are shown here:

```java
byte byteValue( )
double doubleValue( )
float floatValue( )
int intValue( )
long longValue( )
short shortValue( )
```

The values returned by these methods might be rounded, truncated, or result in a “garbage” value due to the effects of a narrowing conversion. `Number` has concrete subclasses that hold explicit values of each primitive numeric type: `Double`, `Float`, `Byte`, `Short`, `Integer`, and `Long`.

**Double and Float**
Double and Float are wrappers for floating-point values of type double and float, respectively. The constructors for Float are shown here:

    Float(double num)
    Float(float num)
    Float(String str) throws NumberFormatException

As you can see, Float objects can be constructed with values of type float or double. They can also be constructed from the string representation of a floating-point number. Beginning with JDK 9, these constructors have been deprecated. The valueOf() method is the recommended alternative.

    The constructors for Double are shown here:

    Double(double num)
    Double(String str) throws NumberFormatException

Double objects can be constructed with a double value or a string containing a floating-point value. Beginning with JDK 9, these constructors have been deprecated. The valueOf() method is the recommended alternative.

    The methods defined by Float include those shown in Table 18-1. The methods defined by Double include those shown in Table 18-2. Both Float and Double define the following constants:
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>byte byteValue( )</td>
<td>Returns the value of the invoking object as a byte.</td>
</tr>
<tr>
<td>static int compare(float num1, float num2)</td>
<td>Compares the values of num1 and num2. Returns 0 if the values are equal. Returns a negative value if num1 is less than num2. Returns a positive value if num1 is greater than num2.</td>
</tr>
<tr>
<td>int compareTo(Float f)</td>
<td>Compares the numerical value of the invoking object with that of f. Returns 0 if the values are equal. Returns a negative value if the invoking object has a lower value. Returns a positive value if the invoking object has a greater value.</td>
</tr>
<tr>
<td>double doubleValue( )</td>
<td>Returns the value of the invoking object as a double.</td>
</tr>
<tr>
<td>boolean equals(Object FloatObj)</td>
<td>Returns true if the invoking Float object is equivalent to FloatObj. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static int floatToIntBits(float num)</td>
<td>Returns the IEEE-compatible, single-precision bit pattern that corresponds to num.</td>
</tr>
<tr>
<td>static int floatToRawIntBits(float num)</td>
<td>Returns the IEEE-compatible single-precision bit pattern that corresponds to num. A NaN value is preserved.</td>
</tr>
<tr>
<td>float floatValue( )</td>
<td>Returns the value of the invoking object as a float.</td>
</tr>
<tr>
<td>int hashCode( )</td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td>static int hashCode(float num)</td>
<td>Returns the hash code for num.</td>
</tr>
<tr>
<td>static float intBitsToFloat(int num)</td>
<td>Returns float equivalent of the IEEE-compatible, single-precision bit pattern specified by num.</td>
</tr>
<tr>
<td>int intValue( )</td>
<td>Returns the value of the invoking object as an int.</td>
</tr>
<tr>
<td>static boolean isFinite(float num)</td>
<td>Returns true if num is not NaN and is not infinite.</td>
</tr>
<tr>
<td>boolean isInfinite( )</td>
<td>Returns true if the invoking object contains an infinite value. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isInfinite(float num)</td>
<td>Returns true if num specifies an infinite value. Otherwise, it returns false.</td>
</tr>
<tr>
<td>boolean isNaN( )</td>
<td>Returns true if the invoking object contains a value that is not a number. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isNaN(float num)</td>
<td>Returns true if num specifies a value that is not a number. Otherwise, it returns false.</td>
</tr>
<tr>
<td>long longValue( )</td>
<td>Returns the value of the invoking object as a long.</td>
</tr>
<tr>
<td>static float max(float val, float val2)</td>
<td>Returns the maximum of val and val2.</td>
</tr>
<tr>
<td>static float min(float val, float val2)</td>
<td>Returns the minimum of val and val2.</td>
</tr>
<tr>
<td>static float parseFloat(String str) throws NumberFormatException</td>
<td>Returns the float equivalent of the number contained in the string specified by str using radix 10.</td>
</tr>
<tr>
<td>short shortValue( )</td>
<td>Returns the value of the invoking object as a short.</td>
</tr>
<tr>
<td>Method Name</td>
<td>Description</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td><code>static float sum(float val, float val2)</code></td>
<td>Returns the result of <code>val + val2</code>.</td>
</tr>
<tr>
<td><code>static String toHexString(float num)</code></td>
<td>Returns a string containing the value of <code>num</code> in hexadecimal format.</td>
</tr>
<tr>
<td><code>String toString()</code></td>
<td>Returns the string equivalent of the invoking object.</td>
</tr>
<tr>
<td><code>static String toString(float num)</code></td>
<td>Returns the string equivalent of the value specified by <code>num</code>.</td>
</tr>
<tr>
<td><code>static Float valueOf(float num)</code></td>
<td>Returns a <code>Float</code> object containing the value passed in <code>num</code>.</td>
</tr>
<tr>
<td><code>static Float valueOf(String str)</code></td>
<td>Returns the <code>Float</code> object that contains the value specified by the string in <code>str</code>.</td>
</tr>
<tr>
<td><code>throws NumberFormatException</code></td>
<td></td>
</tr>
</tbody>
</table>

**Table 18-1** The Methods Defined by `Float`
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>byte byteValue( )</td>
<td>Returns the value of the invoking object as a <strong>byte</strong>.</td>
</tr>
<tr>
<td>static int compare(double *num1,</td>
<td>Compares the values of <em>num1</em> and <em>num2</em>. Returns 0 if the values are</td>
</tr>
<tr>
<td>double <em>num2</em>)</td>
<td>equal. Returns a negative value if <em>num1</em> is less than <em>num2</em>. Returns a</td>
</tr>
<tr>
<td></td>
<td>positive value if <em>num1</em> is greater than <em>num2</em>.</td>
</tr>
<tr>
<td>int compareTo(Double <em>d</em>)</td>
<td>Compares the numerical value of the invoking object with that of <em>d</em>.</td>
</tr>
<tr>
<td></td>
<td>Returns 0 if the values are equal. Returns a negative value if the invoking</td>
</tr>
<tr>
<td></td>
<td>object has a lower value. Returns a positive value if the invoking object</td>
</tr>
<tr>
<td></td>
<td>has a greater value.</td>
</tr>
<tr>
<td>static long doubleToLongBits(double *num)</td>
<td>Returns the IEEE-compatible, double-precision bit pattern that corresponds</td>
</tr>
<tr>
<td></td>
<td>to <em>num</em>. A NaN value is preserved.</td>
</tr>
<tr>
<td>static long doubleToRawLongBits(double *num)</td>
<td>Returns the IEEE-compatible double-precision bit pattern that corresponds</td>
</tr>
<tr>
<td></td>
<td>to <em>num</em>. A NaN value is preserved.</td>
</tr>
<tr>
<td>double doubleValue( )</td>
<td>Returns the value of the invoking object as a <strong>double</strong>.</td>
</tr>
<tr>
<td>boolean equals(Object *DoubleObj)</td>
<td>Returns <strong>true</strong> if the invoking <strong>Double</strong> object is equivalent to <em>DoubleObj</em></td>
</tr>
<tr>
<td></td>
<td>. Otherwise, it returns <strong>false</strong>.</td>
</tr>
<tr>
<td>float floatValue( )</td>
<td>Returns the value of the invoking object as a <strong>float</strong>.</td>
</tr>
<tr>
<td>int hashCode( )</td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td>static int hashCode(double *num)</td>
<td>Returns the hash code for <em>num</em>.</td>
</tr>
<tr>
<td>int intValue( )</td>
<td>Returns the value of the invoking object as an <strong>int</strong>.</td>
</tr>
<tr>
<td>static boolean isFinite(double *num)</td>
<td>Returns <strong>true</strong> if <em>num</em> is not NaN and is not infinite.</td>
</tr>
<tr>
<td>boolean isInfinite( )</td>
<td>Returns <strong>true</strong> if the invoking object contains an infinite value. Otherwise, it returns <strong>false</strong>.</td>
</tr>
<tr>
<td>-----------------------</td>
<td>----------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>static boolean isInfinite(double num)</td>
<td>Returns <strong>true</strong> if <em>num</em> specifies an infinite value. Otherwise, it returns <strong>false</strong>.</td>
</tr>
<tr>
<td>boolean isNaN( )</td>
<td>Returns <strong>true</strong> if the invoking object contains a value that is not a number. Otherwise, it returns <strong>false</strong>.</td>
</tr>
<tr>
<td>static boolean isNaN(double num)</td>
<td>Returns <strong>true</strong> if <em>num</em> specifies a value that is not a number. Otherwise, it returns <strong>false</strong>.</td>
</tr>
<tr>
<td>static double longBitsToDouble(long num)</td>
<td>Returns <strong>double</strong> equivalent of the IEEE-compatible, double-precision bit pattern specified by <em>num</em>.</td>
</tr>
<tr>
<td>long longValue( )</td>
<td>Returns the value of the invoking object as a <strong>long</strong>.</td>
</tr>
<tr>
<td>static double max(double val, double val2)</td>
<td>Returns the maximum of <em>val</em> and <em>val2</em>.</td>
</tr>
<tr>
<td>static double min(double val, double val2)</td>
<td>Returns the minimum of <em>val</em> and <em>val2</em>.</td>
</tr>
<tr>
<td>static double parseDouble(String str) throws NumberFormatException</td>
<td>Returns the <strong>double</strong> equivalent of the number contained in the string specified by <em>str</em> using radix 10.</td>
</tr>
<tr>
<td>short shortValue( )</td>
<td>Returns the value of the invoking object as a <strong>short</strong>.</td>
</tr>
<tr>
<td>static double sum(double val, double val2)</td>
<td>Returns the result of <em>val</em> + <em>val2</em>.</td>
</tr>
<tr>
<td>static String toHexString(double num)</td>
<td>Returns a string containing the value of <em>num</em> in hexadecimal format.</td>
</tr>
<tr>
<td>String toString( )</td>
<td>Returns the string equivalent of the invoking object.</td>
</tr>
<tr>
<td>static String toString(double num)</td>
<td>Returns the string equivalent of the value specified by <em>num</em>.</td>
</tr>
<tr>
<td>static Double valueOf(double num)</td>
<td>Returns a <strong>Double</strong> object containing the value passed in <em>num</em>.</td>
</tr>
<tr>
<td>static Double valueOf(String str) throws NumberFormatException</td>
<td>Returns a <strong>Double</strong> object that contains the value specified by the string in <em>str</em>.</td>
</tr>
</tbody>
</table>

**Table 18-2**  The Methods Defined by **Double**
The following example creates two `Double` objects—one by using a `double` value and the other by passing a string that can be parsed as a `double`:

```java
class DoubleDemo {
    public static void main(String args[]) {
        Double d1 = Double.valueOf(3.14159);
        Double d2 = Double.valueOf("314159E-5");

        System.out.println(d1 + " = " + d2 + " -> " + d1.equals(d2));
    }
}
```

As you can see from the following output, both versions of `valueOf()` created identical `Double` instances, as shown by the `equals()` method returning `true`:

```
3.14159 = 3.14159 -> true
```

### Understanding `isInfinite()` and `isNaN()`

`Float` and `Double` provide the methods `isInfinite()` and `isNaN()`, which help when manipulating two special `double` and `float` values. These methods test for two unique values defined by the IEEE floating-point specification: infinity and NaN (not a number). `isInfinite()` returns `true` if the value being tested is infinitely large or small in magnitude. `isNaN()` returns `true` if the value being tested is not a number.

The following example creates two `Double` objects; one is infinite, and the other
is not a number:

```java
// Demonstrate isInfinite() and isNaN()  
class InfNaN {  
    public static void main(String args[]) {  
        Double d1 = Double.valueOf(1/0.);  
        Double d2 = Double.valueOf(0/0.);  

        System.out.println(d1 + " ": " + d1.isInfinite() + ", " + d1 isNaN());  
        System.out.println(d2 + " ": " + d2.isInfinite() + ", " + d2 isNaN());  
    }  
}
```

This program generates the following output:

```
Infinity: true, false  
NaN: false, true
```

**Byte, Short, Integer, and Long**

The Byte, Short, Integer, and Long classes are wrappers for byte, short, int, and long integer types, respectively. Their constructors are shown here:

- Byte(byte `num`)  
  Byte(String `str`) throws NumberFormatException  

- Short(short `num`)  
  Short(String `str`) throws NumberFormatException  

- Integer(int `num`)  
  Integer(String `str`) throws NumberFormatException  

- Long(long `num`)  
  Long(String `str`) throws NumberFormatException  

As you can see, these objects can be constructed from numeric values or from strings that contain valid whole number values. Beginning with JDK 9, these constructors have been deprecated. The `valueOf()` method is the recommended alternative.

The methods defined by these classes are shown in Tables 18-3 through 18-6. As you can see, they define methods for parsing integers from strings and converting strings back into integers. Variants of these methods allow you to specify the `radix`,
or numeric base, for conversion. Common radixes are 2 for binary, 8 for octal, 10 for decimal, and 16 for hexadecimal.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>byte byteValue( )</td>
<td>Returns the value of the invoking object as a <code>byte</code>.</td>
</tr>
<tr>
<td>static int compare(byte num1, byte num2)</td>
<td>Compares the values of <code>num1</code> and <code>num2</code>. Returns 0 if the values are equal.</td>
</tr>
<tr>
<td>int compareTo(Byte b)</td>
<td>Compares the numerical value of the invoking object with that of <code>b</code>.</td>
</tr>
<tr>
<td>static int compareUnsigned(byte num1,</td>
<td>Performs an unsigned comparison of <code>num1</code> and <code>num2</code>. Returns 0 if the</td>
</tr>
<tr>
<td>byte num2)</td>
<td>values are equal. Returns a negative value if <code>num1</code> is less than <code>num2</code>.</td>
</tr>
<tr>
<td>static Byte decode(String str)</td>
<td>Returns a <code>Byte</code> object that contains the value specified by the string in <code>str</code>.</td>
</tr>
<tr>
<td>throws NumberFormatException</td>
<td></td>
</tr>
<tr>
<td>double doubleValue( )</td>
<td>Returns the value of the invoking object as a <code>double</code>.</td>
</tr>
<tr>
<td>boolean equals(Object ByteObj)</td>
<td>Returns <code>true</code> if the invoking <code>Byte</code> object is equivalent to <code>ByteObj</code>.</td>
</tr>
<tr>
<td>float floatValue()</td>
<td>Otherwise, it returns <code>false</code>.</td>
</tr>
<tr>
<td>int intValue( )</td>
<td>Returns the value of the invoking object as an <code>int</code>.</td>
</tr>
<tr>
<td>long longValue( )</td>
<td>Returns the value of the invoking object as a <code>long</code>.</td>
</tr>
<tr>
<td>static byte parseByte(String str)</td>
<td>Returns the <code>byte</code> equivalent of the number contained in the string</td>
</tr>
<tr>
<td>throws NumberFormatException</td>
<td>specified by <code>str</code> using radix 10.</td>
</tr>
<tr>
<td>static byte parseByte(String str, int radix)</td>
<td>Returns the <code>byte</code> equivalent of the number contained in the string</td>
</tr>
<tr>
<td>throws NumberFormatException</td>
<td>specified by <code>str</code> using the specified radix.</td>
</tr>
<tr>
<td>short shortValue( )</td>
<td>Returns the value of the invoking object as a <code>short</code>.</td>
</tr>
<tr>
<td>String toString( )</td>
<td>Returns a string that contains the decimal equivalent of the invoking</td>
</tr>
<tr>
<td>static String toString(byte num)</td>
<td>object.</td>
</tr>
<tr>
<td>static String toString(byte num)</td>
<td>Returns a string that contains the decimal equivalent of <code>num</code>.</td>
</tr>
<tr>
<td>static int toUnsignedInt(byte val)</td>
<td>Returns the value of <code>val</code> as an unsigned integer.</td>
</tr>
<tr>
<td>static long toUnsignedLong(byte val)</td>
<td>Returns the value of <code>val</code> as an unsigned long integer.</td>
</tr>
<tr>
<td>static Byte valueOff(byte num)</td>
<td>Returns a <code>Byte</code> object containing the value passed in <code>num</code>.</td>
</tr>
<tr>
<td>static Byte valueOff(String str)</td>
<td>Returns a <code>Byte</code> object that contains the value specified by the string</td>
</tr>
<tr>
<td>throws NumberFormatException</td>
<td>in <code>str</code>.</td>
</tr>
<tr>
<td>static Byte valueOff(String str, int radix)</td>
<td>Returns a <code>Byte</code> object that contains the value specified by the string</td>
</tr>
<tr>
<td>throws NumberFormatException</td>
<td>in <code>str</code> using the specified <code>radix</code>.</td>
</tr>
</tbody>
</table>
Table 18-3  The Methods Defined by Byte
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>byte byteValue( )</td>
<td>Returns the value of the invoking object as a byte.</td>
</tr>
<tr>
<td>static int compare(short num1, short num2)</td>
<td>Compares the values of num1 and num2. Returns 0 if the values are equal. Returns a negative value if num1 is less than num2. Returns a positive value if num1 is greater than num2.</td>
</tr>
<tr>
<td>int compareTo(Short s)</td>
<td>Compares the numerical value of the invoking object with that of s. Returns 0 if the values are equal. Returns a negative value if the invoking object has a lower value. Returns a positive value if the invoking object has a greater value.</td>
</tr>
<tr>
<td>static int compareUnsigned(short num1, short num2)</td>
<td>Performs an unsigned comparison of num1 and num2. Returns 0 if the values are equal. Returns a negative value if num1 is less than num2. Returns a positive value if num1 is greater than num2. (Added by JDK 9.)</td>
</tr>
<tr>
<td>static Short decode(String str) throws NumberFormatException</td>
<td>Returns a Short object that contains the value specified by the string in str.</td>
</tr>
<tr>
<td>double doubleValue( )</td>
<td>Returns the value of the invoking object as a double.</td>
</tr>
<tr>
<td>boolean equals(Object ShortObj)</td>
<td>Returns true if the invoking Short object is equivalent to ShortObj. Otherwise, it returns false.</td>
</tr>
<tr>
<td>float floatValue( )</td>
<td>Returns the value of the invoking object as a float.</td>
</tr>
<tr>
<td>int intValue( )</td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td>int hashCode( )</td>
<td>Returns the hash code for num.</td>
</tr>
<tr>
<td>long longValue( )</td>
<td>Returns the value of the invoking object as an int.</td>
</tr>
<tr>
<td>static short parseShort(String str) throws NumberFormatException</td>
<td>Returns the short equivalent of the number contained in the string specified by str using radix 10.</td>
</tr>
<tr>
<td>static short parseShort(String str, int radix) throws NumberFormatException</td>
<td>Returns the short equivalent of the number contained in the string specified by str using the specified radix.</td>
</tr>
<tr>
<td>static short reverseBytes(short num)</td>
<td>Exchanges the high- and low-order bytes of num and returns the result.</td>
</tr>
<tr>
<td>short shortValue( )</td>
<td>Returns the value of the invoking object as a short.</td>
</tr>
<tr>
<td>String toString( )</td>
<td>Returns a string that contains the decimal equivalent of the invoking object.</td>
</tr>
<tr>
<td>static String toString(short num)</td>
<td>Returns a string that contains the decimal equivalent of num.</td>
</tr>
<tr>
<td>static int toUnsignedInt(short val)</td>
<td>Returns the value of val as an unsigned integer.</td>
</tr>
<tr>
<td>static long toUnsignedLong(short val)</td>
<td>Returns the value of val as an unsigned long integer.</td>
</tr>
<tr>
<td>static Short valueOf(short num)</td>
<td>Returns a Short object containing the value passed in num.</td>
</tr>
<tr>
<td>static Short valueOf(String str) throws NumberFormatException</td>
<td>Returns a Short object that contains the value specified by the string in str using radix 10.</td>
</tr>
<tr>
<td>static Short valueOf(String str, int radix) throws NumberFormatException</td>
<td>Returns a Short object that contains the value specified by the string in str using the specified radix.</td>
</tr>
</tbody>
</table>
Table 18-4  The Methods Defined by Short
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static int bitCount(int num)</td>
<td>Returns the number of set bits in num.</td>
</tr>
<tr>
<td>byte byteValue()</td>
<td>Returns the value of the invoking object as a byte.</td>
</tr>
<tr>
<td>static int compare(int num1, int num2)</td>
<td>Compares the values of num1 and num2. Returns 0 if the values are equal.</td>
</tr>
<tr>
<td></td>
<td>Returns a negative value if num1 is less than num2. Returns a positive value</td>
</tr>
<tr>
<td></td>
<td>if num1 is greater than num2.</td>
</tr>
<tr>
<td>int compareTo(Integer i)</td>
<td>Compares the numerical value of the invoking object with that of i.</td>
</tr>
<tr>
<td></td>
<td>Returns 0 if the values are equal. Returns a negative value if the</td>
</tr>
<tr>
<td></td>
<td>invoking object has a lower value. Returns a positive value if the</td>
</tr>
<tr>
<td></td>
<td>invoking object has a greater value.</td>
</tr>
<tr>
<td>static int compareUnsigned(int num1, int num2)</td>
<td>Performs an unsigned comparison of num1 and num2. Returns 0 if the values</td>
</tr>
<tr>
<td></td>
<td>are equal. Returns a negative value if num1 is less than num2. Returns a</td>
</tr>
<tr>
<td></td>
<td>positive value if num1 is greater than num2.</td>
</tr>
<tr>
<td>static Integer decode(String str)</td>
<td>Returns an Integer object that contains the value specified by the string</td>
</tr>
<tr>
<td>throws NumberFormatException</td>
<td>in str.</td>
</tr>
<tr>
<td>static int divideUnsigned(int dividend, int divisor)</td>
<td>Returns the result, as an unsigned value, of the unsigned division of</td>
</tr>
<tr>
<td></td>
<td>dividend by divisor.</td>
</tr>
<tr>
<td>double doubleValue()</td>
<td>Returns the value of the invoking object as a double.</td>
</tr>
<tr>
<td>boolean equals(Object IntegerObj)</td>
<td>Returns true if the invoking Integer object is equivalent to IntegerObj.</td>
</tr>
<tr>
<td></td>
<td>Otherwise, it returns false.</td>
</tr>
<tr>
<td>float floatValue()</td>
<td>Returns the value of the invoking object as a float.</td>
</tr>
<tr>
<td>static Integer getInteger(String propertyName)</td>
<td>Returns the value associated with the environmental property specified by</td>
</tr>
<tr>
<td></td>
<td>propertyName. A null is returned on failure.</td>
</tr>
<tr>
<td>static Integer getInteger(String propertyName,</td>
<td>Returns the value associated with the environmental property specified by</td>
</tr>
<tr>
<td>int default)</td>
<td>propertyName. The value of default is returned on failure.</td>
</tr>
<tr>
<td>static Integer getInteger(String propertyName,</td>
<td>Returns the value associated with the environmental property specified by</td>
</tr>
<tr>
<td>Integer default)</td>
<td>propertyName. The value of default is returned on failure.</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td>static int hashCode(int num)</td>
<td>Returns the hash code for num.</td>
</tr>
<tr>
<td>static int highestOneBit(int num)</td>
<td>Determines the position of the highest order set bit in num. It returns</td>
</tr>
<tr>
<td></td>
<td>a value in which only this bit is set. If no bit is set to one, then zero</td>
</tr>
<tr>
<td></td>
<td>is returned.</td>
</tr>
<tr>
<td>int intValue()</td>
<td>Returns the value of the invoking object as an int.</td>
</tr>
<tr>
<td>long longValue()</td>
<td>Returns the value of the invoking object as a long.</td>
</tr>
<tr>
<td>static int lowestOneBit(int num)</td>
<td>Determines the position of the lowest order set bit in num. It returns a</td>
</tr>
<tr>
<td></td>
<td>value in which only this bit is set. If no bit is set to one, then zero is</td>
</tr>
<tr>
<td></td>
<td>returned.</td>
</tr>
<tr>
<td>static int max(int val, int val2)</td>
<td>Returns the maximum of val and val2.</td>
</tr>
<tr>
<td>static int min(int val, int val2)</td>
<td>Returns the minimum of val and val2.</td>
</tr>
<tr>
<td>static int numberOfLeadingZeros(int num)</td>
<td>Returns the number of high-order zero bits that precede the first high-</td>
</tr>
<tr>
<td></td>
<td>order set bit in num. If num is zero, 32 is returned.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td><code>static int numberOfTrailingZeros(int num)</code></td>
<td>Returns the number of low-order zero bits that precede the first low-order set bit in <code>num</code>. If <code>num</code> is zero, 32 is returned.</td>
</tr>
<tr>
<td><code>static int parseInt(CharSequence chars, int startIdx, int stopIdx, int radix)</code></td>
<td>Throws <code>NumberFormatException</code> &lt;br&gt; Returns the integer equivalent of the number contained in the sequence specified by <code>chars</code>, between the indices <code>startIdx</code> and <code>stopIdx-1</code>, using the specified <code>radix</code>. (Added by JDK 9.)</td>
</tr>
<tr>
<td><code>static int parseInt(String str)</code></td>
<td>Throws <code>NumberFormatException</code> &lt;br&gt; Returns the integer equivalent of the number contained in the string specified by <code>str</code> using radix 10.</td>
</tr>
<tr>
<td><code>static int parseInt(String str, int radix)</code></td>
<td>Throws <code>NumberFormatException</code> &lt;br&gt; Returns the integer equivalent of the number contained in the string specified by <code>str</code> using the specified <code>radix</code>.</td>
</tr>
<tr>
<td><code>static int parseUnsignedInt(CharSequence chars, int startIdx, int stopIdx, int radix)</code></td>
<td>Throws <code>NumberFormatException</code> &lt;br&gt; Returns the integer equivalent of the unsigned number contained in the sequence specified by <code>chars</code>, between the indices <code>startIdx</code> and <code>stopIdx-1</code>, using the specified <code>radix</code>. (Added by JDK 9.)</td>
</tr>
<tr>
<td><code>static int parseUnsignedInt(String str)</code></td>
<td>Throws <code>NumberFormatException</code> &lt;br&gt; Returns the unsigned integer equivalent of the number contained in the string specified by <code>str</code> using radix 10.</td>
</tr>
<tr>
<td><code>static int parseUnsignedInt(String str, int radix)</code></td>
<td>Throws <code>NumberFormatException</code> &lt;br&gt; Returns the unsigned integer equivalent of the number contained in the string specified by <code>str</code> using the specified <code>radix</code>.</td>
</tr>
<tr>
<td><code>static int remainderUnsigned(int dividend, int divisor)</code></td>
<td>Returns the remainder, as an unsigned value, of the unsigned division of <code>dividend</code> by <code>divisor</code>.</td>
</tr>
<tr>
<td><code>static int reverse(int num)</code></td>
<td>Reverses the order of the bits in <code>num</code> and returns the result.</td>
</tr>
<tr>
<td><code>static int reverseBytes(int num)</code></td>
<td>Reverses the order of the bytes in <code>num</code> and returns the result.</td>
</tr>
<tr>
<td><code>static int rotateLeft(int num, int n)</code></td>
<td>Returns the result of rotating <code>num</code> left <code>n</code> positions.</td>
</tr>
<tr>
<td><code>static int rotateRight(int num, int n)</code></td>
<td>Returns the result of rotating <code>num</code> right <code>n</code> positions.</td>
</tr>
<tr>
<td><code>short shortValue()</code></td>
<td>Returns the value of the invoking object as a <code>short</code>.</td>
</tr>
<tr>
<td><code>static int signum(int num)</code></td>
<td>Returns -1 if <code>num</code> is negative, 0 if it is zero, and 1 if it is positive.</td>
</tr>
<tr>
<td><code>static int sum(int val, int val2)</code></td>
<td>Returns the result of <code>val + val2</code>.</td>
</tr>
<tr>
<td><code>static String toBinaryString(int num)</code></td>
<td>Returns a string that contains the binary equivalent of <code>num</code>.</td>
</tr>
<tr>
<td><code>static String toHexString(int num)</code></td>
<td>Returns a string that contains the hexadecimal equivalent of <code>num</code>.</td>
</tr>
<tr>
<td><code>static String toOctalString(int num)</code></td>
<td>Returns a string that contains the octal equivalent of <code>num</code>.</td>
</tr>
<tr>
<td><code>String toString()</code></td>
<td>Returns a string that contains the decimal equivalent of the invoking object.</td>
</tr>
<tr>
<td><code>static String toString(int num)</code></td>
<td>Returns a string that contains the decimal equivalent of <code>num</code>.</td>
</tr>
<tr>
<td><code>static String toString(int num, int radix)</code></td>
<td>Returns a string that contains the decimal equivalent of <code>num</code> using the specified <code>radix</code>.</td>
</tr>
<tr>
<td><code>static long toUnsignedLong(int val)</code></td>
<td>Returns the value of <code>val</code> as an unsigned long integer.</td>
</tr>
<tr>
<td><code>static String toUnsignedString(int val)</code></td>
<td>Returns a string that contains the decimal value of <code>val</code> as an unsigned integer.</td>
</tr>
<tr>
<td>Method Description</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>static String toUnsignedString(int val, int radix)</td>
<td>Returns a string that contains the value of val as an unsigned integer in the radix specified by radix.</td>
</tr>
<tr>
<td>static Integer valueOf(int num)</td>
<td>Returns an Integer object containing the value passed in num.</td>
</tr>
<tr>
<td>static Integer valueOf(String str) throws NumberFormatException</td>
<td>Returns an Integer object that contains the value specified by the string in str.</td>
</tr>
<tr>
<td>static Integer valueOf(String str, int radix) throws NumberFormatException</td>
<td>Returns an Integer object that contains the value specified by the string in str using the specified radix.</td>
</tr>
</tbody>
</table>

**Table 18-5** The Methods Defined by Integer
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static int bitCount(long num)</td>
<td>Returns the number of set bits in num.</td>
</tr>
<tr>
<td>byte byteValue()</td>
<td>Returns the value of the invoking object as a byte.</td>
</tr>
<tr>
<td>static int compare(long num1, long num2)</td>
<td>Compares the values of num1 and num2. Returns 0 if the values are equal. Returns a negative value if num1 is less than num2. Returns a positive value if num1 is greater than num2.</td>
</tr>
<tr>
<td>int compareTo(Long l)</td>
<td>Compares the numerical value of the invoking object with that of l. Returns 0 if the values are equal. Returns a negative value if the invoking object has a lower value. Returns a positive value if the invoking object has a greater value.</td>
</tr>
<tr>
<td>static int compareUnsigned(long num1, long num2)</td>
<td>Performs an unsigned comparison of num1 and num2. Returns 0 if the values are equal. Returns a negative value if num1 is less than num2. Returns a positive value if num1 is greater than num2.</td>
</tr>
<tr>
<td>static Long decode(String str) throws NumberFormatException</td>
<td>Returns a Long object that contains the value specified by the string in str.</td>
</tr>
<tr>
<td>static long divideUnsigned(long dividend, long divisor)</td>
<td>Returns the result, as an unsigned value, of the unsigned division of dividend by divisor.</td>
</tr>
<tr>
<td>double doubleValue()</td>
<td>Returns the value of the invoking object as a double.</td>
</tr>
<tr>
<td>boolean equals(Object LongObj)</td>
<td>Returns true if the invoking Long object is equivalent to LongObj. Otherwise, it returns false.</td>
</tr>
<tr>
<td>float floatValue()</td>
<td>Returns the value of the invoking object as a float.</td>
</tr>
<tr>
<td>static Long getLong(String propertyName)</td>
<td>Returns the value associated with the environmental property specified by propertyName. A null is returned on failure.</td>
</tr>
<tr>
<td>static Long getLong(String propertyName, long default)</td>
<td>Returns the value associated with the environmental property specified by propertyName. The value of default is returned on failure.</td>
</tr>
<tr>
<td>static Long getLong(String propertyName, Long default)</td>
<td>Returns the value associated with the environmental property specified by propertyName. The value of default is returned on failure.</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td>static int hashCode(long num)</td>
<td>Returns the hash code for num.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td><code>static long highestOneBit(long num)</code></td>
<td>Determines the position of the highest-order set bit in <code>num</code>. It returns a value in which only this bit is set. If no bit is set to one, then zero is returned.</td>
</tr>
<tr>
<td><code>int intValue()</code></td>
<td>Returns the value of the invoking object as an <code>int</code>.</td>
</tr>
<tr>
<td><code>long longValue()</code></td>
<td>Returns the value of the invoking object as a <code>long</code>.</td>
</tr>
<tr>
<td><code>static long lowestOneBit(long num)</code></td>
<td>Determines the position of the lowest-order set bit in <code>num</code>. It returns a value in which only this bit is set. If no bit is set to one, then zero is returned.</td>
</tr>
<tr>
<td><code>static long max(long val, long val2)</code></td>
<td>Returns the maximum of <code>val</code> and <code>val2</code>.</td>
</tr>
<tr>
<td><code>static long min(long val, long val2)</code></td>
<td>Returns the minimum of <code>val</code> and <code>val2</code>.</td>
</tr>
<tr>
<td><code>static int numberOfLeadingZeros(long num)</code></td>
<td>Returns the number of high-order zero bits that precede the first high-order set bit in <code>num</code>. If <code>num</code> is zero, 64 is returned.</td>
</tr>
<tr>
<td><code>static int numberOfTrailingZeros(long num)</code></td>
<td>Returns the number of low-order zero bits that precede the first low-order set bit in <code>num</code>. If <code>num</code> is zero, 64 is returned.</td>
</tr>
<tr>
<td><code>static long parseLong(CharSequence chars, int startldx, int stopldx, int radix)</code></td>
<td>Returns the <code>long</code> equivalent of the number contained in the sequence specified by <code>chars</code>, between the indices <code>startldx</code> and <code>stopldx-1</code>, using the specified <code>radix</code>. (Added by JDK 9.)</td>
</tr>
<tr>
<td><code>static long parseLong(String str)</code></td>
<td>Returns the <code>long</code> equivalent of the number contained in the string specified by <code>str</code> using radix 10.</td>
</tr>
<tr>
<td><code>static long parseLong(String str, int radix)</code></td>
<td>Returns the <code>long</code> equivalent of the number contained in the string specified by <code>str</code> using the specified <code>radix</code>.</td>
</tr>
<tr>
<td><code>static long parseUnsignedLong(CharSequence chars, int startldx, int stopldx, int radix)</code></td>
<td>Returns the <code>long</code> equivalent of the unsigned number contained in the sequence specified by <code>chars</code>, between the indices <code>startldx</code> and <code>stopldx-1</code>, using the specified <code>radix</code>. (Added by JDK 9.)</td>
</tr>
<tr>
<td><code>static long parseUnsignedLong(String str, int radix)</code></td>
<td>Returns the unsigned integer equivalent of the number contained in the string specified by <code>str</code> using the radix 10.</td>
</tr>
<tr>
<td><code>static long remainderUnsigned(long dividend, long divisor)</code></td>
<td>Returns the remainder, as an unsigned value, of the unsigned division of <code>dividend</code> by <code>divisor</code>.</td>
</tr>
<tr>
<td><code>static long reverse(long num)</code></td>
<td>Reverses the order of the bits in <code>num</code> and returns the result.</td>
</tr>
<tr>
<td><code>static long reverseBytes(long num)</code></td>
<td>Reverses the order of the bytes in <code>num</code> and returns the result.</td>
</tr>
<tr>
<td><code>static long rotateLeft(long num, int n)</code></td>
<td>Returns the result of rotating <code>num</code> left <code>n</code> positions.</td>
</tr>
<tr>
<td><code>static long rotateRight(long num, int n)</code></td>
<td>Returns the result of rotating <code>num</code> right <code>n</code> positions.</td>
</tr>
<tr>
<td><code>short shortValue()</code></td>
<td>Returns the value of the invoking object as a <code>short</code>.</td>
</tr>
<tr>
<td><code>static int signum(long num)</code></td>
<td>Returns -1 if <code>num</code> is negative, 0 if it is zero, and 1 if it is positive.</td>
</tr>
<tr>
<td><code>static long sum(long val, long val2)</code></td>
<td>Returns the result of <code>val + val2</code>.</td>
</tr>
<tr>
<td><code>static String toString(BigInteger num)</code></td>
<td>Returns a string that contains the binary equivalent of <code>num</code>.</td>
</tr>
</tbody>
</table>
The following constants are defined:

<table>
<thead>
<tr>
<th>Constants</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BYTES</td>
<td>The width of the integer type in bytes</td>
</tr>
<tr>
<td>MIN_VALUE</td>
<td>Minimum value</td>
</tr>
<tr>
<td>MAX_VALUE</td>
<td>Maximum value</td>
</tr>
<tr>
<td>SIZE</td>
<td>The bit width of the wrapped value</td>
</tr>
<tr>
<td>TYPE</td>
<td>The Class object for byte, short, int, or long</td>
</tr>
</tbody>
</table>

### Converting Numbers to and from Strings

One of the most common programming chores is converting the string representation of a number into its internal, binary format. Fortunately, Java provides an easy way to accomplish this. The **Byte**, **Short**, **Integer**, and **Long** classes provide the **parseByte()**, **parseShort()**, **parseInt()**, and **parseLong()** methods, respectively. These methods return the **byte**, **short**, **int**, or **long** equivalent of the numeric string with which they are called. (Similar methods also exist for the **Float** and **Double** classes.)
The following program demonstrates `parseInt( )`. It sums a list of integers entered by the user. It reads the integers using `readLine( )` and uses `parseInt( )` to convert these strings into their `int` equivalents.

```java
/* This program sums a list of numbers entered
   by the user. It converts the string representation
   of each number into an int using parseInt(). */
import java.io.*;

class ParseDemo {
    public static void main(String args[])
        throws IOException {
        // create a BufferedReader using System.in
        BufferedReader br = new
            BufferedReader(new InputStreamReader(System.in));
        String str;
        int i;
        int sum=0;

        System.out.println("Enter numbers, 0 to quit. ");
        do {
            str = br.readLine();
            try {
                i = Integer.parseInt(str);
            } catch (NumberFormatException e) {
                System.out.println("Invalid format");
                i = 0;
            }
            sum += i;
            System.out.println("Current sum is: " + sum);
        } while (i != 0);
    }
}
```

To convert a whole number into a decimal string, use the versions of `toString( )` defined in the `Byte, Short, Integer, or Long` classes. The `Integer` and `Long` classes also provide the methods `toBinaryString( ), toHexString( ), and toOctalString( )`, which convert a value into a binary, hexadecimal, or octal string, respectively.

The following program demonstrates binary, hexadecimal, and octal conversion:
class StringConversions {
    public static void main(String args[]) {
        int num = 19648;
        System.out.println(num + " in binary: " +
                Integer.toBinaryString(num));

        System.out.println(num + " in octal: " +
                Integer.toOctalString(num));

        System.out.println(num + " in hexadecimal: " +
                Integer.toHexString(num));
    }
}

The output of this program is shown here:

    19648 in binary: 100110011000000
    19648 in octal: 46300
    19648 in hexadecimal: 4cc0

Character

Character is a simple wrapper around a char. The constructor for Character is

    Character(char ch)

Here, ch specifies the character that will be wrapped by the Character object being created. Beginning with JDK 9, this constructor has been deprecated. The valueOf() method is the recommended alternative.

To obtain the char value contained in a Character object, call charValue(), shown here:

    char charValue()

It returns the character.

The Character class defines several constants, including the following:
<table>
<thead>
<tr>
<th>Character</th>
<th>The width of a char in bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX_RADIX</td>
<td>The largest radix</td>
</tr>
<tr>
<td>MIN_RADIX</td>
<td>The smallest radix</td>
</tr>
<tr>
<td>MAX_VALUE</td>
<td>The largest character value</td>
</tr>
<tr>
<td>MIN_VALUE</td>
<td>The smallest character value</td>
</tr>
<tr>
<td>TYPE</td>
<td>The Class object for char</td>
</tr>
</tbody>
</table>

**Character** includes several static methods that categorize characters and alter their case. A sampling is shown in Table 18-7. The following example demonstrates several of these methods:

```java
// Demonstrate several Is... methods.

class IsDemo {
    public static void main(String args[]) {
        char a[] = {'a', 'b', '5', '?', 'A', ' '};

        for(int i=0; i<a.length; i++) {
            if(Character.isDigit(a[i]))
                System.out.println(a[i] + " is a digit.");
            if(Character.isLetter(a[i]))
                System.out.println(a[i] + " is a letter.");
            if(Character.isWhitespace(a[i]))
                System.out.println(a[i] + " is whitespace.");
            if(Character.isUpperCase(a[i]))
                System.out.println(a[i] + " is uppercase.");
            if(Character.isLowerCase(a[i]))
                System.out.println(a[i] + " is lowercase.");
        }
    }
}
```
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static boolean isDefined(char ch)</td>
<td>Returns true if ch is defined by Unicode. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isDigit(char ch)</td>
<td>Returns true if ch is a digit. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isIdentifierIgnorable(char ch)</td>
<td>Returns true if ch should be ignored in an identifier. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isISOControl(char ch)</td>
<td>Returns true if ch is an ISO control character. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isJavaIdentifierPart(char ch)</td>
<td>Returns true if ch is allowed as part of a Java identifier (other than the first character). Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isJavaIdentifierStart(char ch)</td>
<td>Returns true if ch is allowed as the first character of a Java identifier. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isLetter(char ch)</td>
<td>Returns true if ch is a letter. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isLetterOrDigit(char ch)</td>
<td>Returns true if ch is a letter or a digit. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isLowerCase(char ch)</td>
<td>Returns true if ch is a lowercase letter. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isMirrored(char ch)</td>
<td>Returns true if ch is a mirrored Unicode character. A mirrored character is one that is reversed for text that is displayed right-to-left.</td>
</tr>
<tr>
<td>static boolean isSpaceChar(char ch)</td>
<td>Returns true if ch is a Unicode space character. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isTitleCase(char ch)</td>
<td>Returns true if ch is a Unicode titlecase character. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isUnicodeIdentifierPart(char ch)</td>
<td>Returns true if ch is allowed as part of a Unicode identifier (other than the first character). Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isUnicodeIdentifierStart(char ch)</td>
<td>Returns true if ch is allowed as the first character of a Unicode identifier. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isUpperCase(char ch)</td>
<td>Returns true if ch is an uppercase letter. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isWhitespace(char ch)</td>
<td>Returns true if ch is whitespace. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static char toLowerCase(char ch)</td>
<td>Returns lowercase equivalent of ch.</td>
</tr>
<tr>
<td>static char toTitleCase(char ch)</td>
<td>Returns titlecase equivalent of ch.</td>
</tr>
<tr>
<td>static char toUpperCase(char ch)</td>
<td>Returns uppercase equivalent of ch.</td>
</tr>
</tbody>
</table>
Character defines two methods, `forDigit()` and `digit()`, that enable you to convert between integer values and the digits they represent. They are shown here:

```java
static char forDigit(int num, int radix)
static int digit(char digit, int radix)
```

`forDigit()` returns the digit character associated with the value of `num`. The radix of the conversion is specified by `radix`. `digit()` returns the integer value associated with the specified character (which is presumably a digit) according to the specified radix. (There is a second form of `digit()` that takes a code point. See the following section for a discussion of code points.)

Another method defined by Character is `compareTo()`, which has the following form:

```java
int compareTo(Character c)
```

It returns zero if the invoking object and `c` have the same value. It returns a negative value if the invoking object has a lower value. Otherwise, it returns a positive value.

Character includes a method called `getDirectionality()` which can be used to determine the direction of a character. Several constants are defined that describe directionality. Most programs will not need to use character directionality.

Character also overrides the `equals()` and `hashCode()` methods.

Two other character-related classes are `Character.Subset`, used to describe a subset of Unicode, and `Character.UnicodeBlock`, which contains Unicode character blocks.

Additions to Character for Unicode Code Point Support

Relatively recently, major additions were made to Character. Beginning with JDK
In the past, all Unicode characters could be held by 16 bits, which is the size of a `char` (and the size of the value encapsulated within a `Character`), because those values ranged from 0 to FFFF. However, the Unicode character set has been expanded, and more than 16 bits are required. Characters can now range from 0 to 10FFFF.

Here are three important terms. A code point is a character in the range 0 to 10FFFF. Characters that have values greater than FFFF are called supplemental characters. The basic multilingual plane (BMP) are those characters between 0 and FFFF.

The expansion of the Unicode character set caused a fundamental problem for Java. Because a supplemental character has a value greater than a `char` can hold, some means of handling the supplemental characters was needed. Java addressed this problem in two ways. First, Java uses two `chars` to represent a supplemental character. The first `char` is called the high surrogate, and the second is called the low surrogate. New methods, such as `codePointAt()`, were provided to translate between code points and supplemental characters.

Secondly, Java overloaded several preexisting methods in the `Character` class. The overloaded forms use `int` rather than `char` data. Because an `int` is large enough to hold any character as a single value, it can be used to store any character. For example, all of the methods in Table 18-7 have overloaded forms that operate on `int`. Here is a sampling:

```java
static boolean isDigit(int cp)
static boolean isLetter(int cp)
static int toLowerCase(int cp)
```

In addition to the methods overloaded to accept code points, `Character` adds methods that provide additional support for code points. A sampling is shown in Table 18-8.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static int charCount(int cp)</td>
<td>Returns 1 if cp can be represented by a single char. It returns 2 if two chars are needed.</td>
</tr>
<tr>
<td>static int codePointAt(CharSequence chars, int loc)</td>
<td>Returns the code point at the location specified by loc.</td>
</tr>
<tr>
<td>static int codePointAt(char chars[], int loc)</td>
<td>Returns the code point at the location specified by loc.</td>
</tr>
<tr>
<td>static int codePointBefore(CharSequence chars, int loc)</td>
<td>Returns the code point at the location that precedes that specified by loc.</td>
</tr>
<tr>
<td>static int codePointBefore(char chars[], int loc)</td>
<td>Returns the code point at the location that precedes that specified by loc.</td>
</tr>
<tr>
<td>static boolean isBmpCodePoint(int cp)</td>
<td>Returns true if cp is part of the basic multilingual plane and false otherwise.</td>
</tr>
<tr>
<td>static boolean isHighSurrogate(char ch)</td>
<td>Returns true if ch contains a valid high surrogate character.</td>
</tr>
<tr>
<td>static boolean isLowSurrogate(char ch)</td>
<td>Returns true if ch contains a valid low surrogate character.</td>
</tr>
<tr>
<td>static boolean isSupplementaryCodePoint(int cp)</td>
<td>Returns true if cp contains a supplemental character.</td>
</tr>
<tr>
<td>static boolean isSurrogatePair(char highCh, char lowCh)</td>
<td>Returns true if highCh and lowCh form a valid surrogate pair.</td>
</tr>
<tr>
<td>static boolean isValidCodePoint(int cp)</td>
<td>Returns true if cp contains a valid code point.</td>
</tr>
<tr>
<td>static char[] toChars(int cp)</td>
<td>Converts the code point in cp into its char equivalent, which might require two chars. An array holding the result is returned.</td>
</tr>
<tr>
<td>static int toChars(int cp, char target[], int loc)</td>
<td>Converts the code point in cp into its char equivalent, storing the result in target, beginning at loc. Returns 1 if cp can be represented by a single char. It returns 2 otherwise.</td>
</tr>
<tr>
<td>static int toCodePoint(char highCh, char lowCh)</td>
<td>Converts highCh and lowCh into their equivalent code point.</td>
</tr>
</tbody>
</table>

**Table 18-8** A Sampling of Methods That Provide Support for 32-Bit Unicode Code Points
**Boolean**

*Boolean* is a very thin wrapper around *boolean* values, which is useful mostly when you want to pass a *boolean* variable by reference. It contains the constants *TRUE* and *FALSE*, which define true and false *Boolean* objects. *Boolean* also defines the *TYPE* field, which is the *Class* object for *boolean*. *Boolean* defines these constructors:

- `Boolean(boolean boolValue)`
- `Boolean(String boolString)`

In the first version, *boolValue* must be either *true* or *false*. In the second version, if *boolString* contains the string "true" (in uppercase or lowercase), then the new *Boolean* object will be *true*. Otherwise, it will be *false*. Beginning with JDK 9, these constructors have been deprecated. The `valueOf()` method is the recommended alternative.

*Boolean* defines the methods shown in Table 18-9.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>boolean booleanValue( )</code></td>
<td>Returns <code>boolean</code> equivalent.</td>
</tr>
<tr>
<td><code>static int compare(boolean b1, boolean b2)</code></td>
<td>Returns zero if <code>b1</code> and <code>b2</code> contain the same value. Returns a positive value if <code>b1</code> is <code>true</code> and <code>b2</code> is <code>false</code>. Otherwise, returns a negative value.</td>
</tr>
<tr>
<td><code>int compareTo(Boolean b)</code></td>
<td>Returns zero if the invoking object and <code>b</code> contain the same value. Returns a positive value if the invoking object is <code>true</code> and <code>b</code> is <code>false</code>. Otherwise, returns a negative value.</td>
</tr>
<tr>
<td><code>boolean equals(Object boolObj)</code></td>
<td>Returns <code>true</code> if the invoking object is equivalent to <code>boolObj</code>. Otherwise, it returns <code>false</code>.</td>
</tr>
<tr>
<td><code>static Boolean getBoolean(String propertyName)</code></td>
<td>Returns <code>true</code> if the system property specified by <code>propertyName</code> is <code>true</code>. Otherwise, it returns <code>false</code>.</td>
</tr>
<tr>
<td><code>int hashCode( )</code></td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td><code>static int hashCode(boolean boolVal)</code></td>
<td>Returns the hash code for <code>boolVal</code>.</td>
</tr>
<tr>
<td><code>static boolean logicalAnd(boolean op1, boolean op2)</code></td>
<td>Performs a logical AND of <code>op1</code> and <code>op2</code> and returns the result.</td>
</tr>
<tr>
<td><code>static boolean logicalOr(boolean op1, boolean op2)</code></td>
<td>Performs a logical OR of <code>op1</code> and <code>op2</code> and returns the result.</td>
</tr>
<tr>
<td><code>static boolean logicalXor(boolean op1, boolean op2)</code></td>
<td>Performs a logical XOR of <code>op1</code> and <code>op2</code> and returns the result.</td>
</tr>
<tr>
<td><code>static boolean parseBoolean(String str)</code></td>
<td>Returns <code>true</code> if <code>str</code> contains the string &quot;true&quot;. Case is not significant. Otherwise, returns <code>false</code>.</td>
</tr>
<tr>
<td><code>String toString( )</code></td>
<td>Returns the string equivalent of the invoking object.</td>
</tr>
<tr>
<td><code>static String toString(boolean boolVal)</code></td>
<td>Returns the string equivalent of <code>boolVal</code>.</td>
</tr>
<tr>
<td><code>static Boolean valueOf(boolean boolVal)</code></td>
<td>Returns the <code>Boolean</code> equivalent of <code>boolVal</code>.</td>
</tr>
<tr>
<td><code>static Boolean valueOf(String boolString)</code></td>
<td>Returns <code>true</code> if <code>boolString</code> contains the string &quot;true&quot; (in uppercase or lowercase). Otherwise, it returns <code>false</code>.</td>
</tr>
</tbody>
</table>

**Table 18-9**  The Methods Defined by `Boolean`  

**Void**  
The Void class has one field, TYPE, which holds a reference to the Class object for
type `void`. You do not create instances of this class.

**Process**

The abstract `Process` class encapsulates a *process*—that is, an executing program. It is used primarily as a superclass for the type of objects created by `exec()` in the `Runtime` class, or by `start()` in the `ProcessBuilder` class. `Process` contains the methods shown in Table 18-10. Notice that beginning with JDK 9, you can obtain a handle to the process in the form of a `ProcessHandle` instance, and that you can obtain information about the process encapsulated in a `ProcessHandle.Info` instance. These offer additional control and information about a process. One particularly interesting piece of information is the amount of CPU time that a process receives. This is obtained by calling `totalCpuDuration()` defined by `ProcessHandle.Info`. Another especially helpful piece of information is obtained by calling `isAlive()` on a `ProcessHandle`. It will return `true` if the process is still executing.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stream &lt;ProcessHandle&gt; children()</td>
<td>Returns a stream that contains ProcessHandle objects that represent the immediate children of the invoking process. (Added by JDK 9.)</td>
</tr>
<tr>
<td>Stream &lt;ProcessHandle&gt; descendants()</td>
<td>Returns a stream that contains ProcessHandle objects that represent both the immediate children of the invoking process, plus all of their descendants. (Added by JDK 9.)</td>
</tr>
<tr>
<td>void destroy()</td>
<td>Terminates the process.</td>
</tr>
<tr>
<td>Process destroyForcibly()</td>
<td>Forces termination of the invoking process. Returns a reference to the process.</td>
</tr>
<tr>
<td>int exitValue()</td>
<td>Returns an exit code obtained from a subprocess.</td>
</tr>
<tr>
<td>InputStream getErrorStream()</td>
<td>Returns an input stream that reads input from the process' err output stream.</td>
</tr>
<tr>
<td>InputStream getInputStream()</td>
<td>Returns an input stream that reads input from the process' out output stream.</td>
</tr>
<tr>
<td>OutputStream getOutputStream()</td>
<td>Returns an output stream that writes output to the process' in input stream.</td>
</tr>
<tr>
<td>ProcessHandle.Info info()</td>
<td>Returns information about the process in the form of a ProcessHandle.Info object. (Added by JDK 9.)</td>
</tr>
<tr>
<td>boolean isAlive()</td>
<td>Returns true if the invoking process is still active. Otherwise, returns false.</td>
</tr>
<tr>
<td>CompletableFuture &lt;Process&gt; onExit()</td>
<td>Returns a CompletableFuture for the invoking process, which can be used to perform tasks at termination. (Added by JDK 9.)</td>
</tr>
<tr>
<td>long pid()</td>
<td>Returns the process ID associated with the invoking process. (Added by JDK 9.)</td>
</tr>
<tr>
<td>boolean supportsNormalTermination()</td>
<td>Determines if a call to destroy() will result in normal or forced termination. Returns true if termination is normal, and false otherwise. (Added by JDK 9.)</td>
</tr>
<tr>
<td>ProcessHandle toHandle()</td>
<td>Returns a handle to the invoking process in the form of a ProcessHandle object. (Added by JDK 9.)</td>
</tr>
<tr>
<td>int waitFor() throws InterruptedException</td>
<td>Returns the exit code returned by the process. This method does not return until the process on which it is called terminates.</td>
</tr>
<tr>
<td>boolean waitFor(long waitTime, TimeUnit timeUnit) throws InterruptedException</td>
<td>Waits for the invoking process to end. The amount of time to wait is specified by waitTime in the units specified by TimeUnit. Returns true if the process has ended and false if the wait time runs out.</td>
</tr>
</tbody>
</table>

Table 18-10  The Methods Defined by Process
Runtime

The **Runtime** class encapsulates the run-time environment. You cannot instantiate a **Runtime** object. However, you can get a reference to the current **Runtime** object by calling the static method **Runtime.getRuntime()**. Once you obtain a reference to the current **Runtime** object, you can call several methods that control the state and behavior of the Java Virtual Machine. Untrusted code typically cannot call any of the **Runtime** methods without raising a **SecurityException**. A sampling of methods defined by **Runtime** are shown in **Table 18-11**.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void addShutdownHook(Thread <code>thrd</code>)</td>
<td>Registers <code>thrd</code> as a thread to be run when the Java Virtual Machine terminates.</td>
</tr>
<tr>
<td>Process exec(String <code>progName</code>)</td>
<td>Executes the program specified by <code>progName</code> as a separate process. An object of type <code>Process</code> is returned that describes the new process.</td>
</tr>
<tr>
<td>Process exec(String <code>progName</code>, String <code>environment</code>[])</td>
<td>Executes the program specified by <code>progName</code> as a separate process with the environment specified by <code>environment</code>. An object of type <code>Process</code> is returned that describes the new process.</td>
</tr>
<tr>
<td>Process exec(String <code>comLineArray</code>[])</td>
<td>Executes the command line specified by the strings in <code>comLineArray</code> as a separate process. An object of type <code>Process</code> is returned that describes the new process.</td>
</tr>
<tr>
<td>Process exec(String <code>comLineArray</code>[], String <code>environment</code>[])</td>
<td>Executes the command line specified by the strings in <code>comLineArray</code> as a separate process with the environment specified by <code>environment</code>. An object of type <code>Process</code> is returned that describes the new process.</td>
</tr>
<tr>
<td>void exit(int <code>exitCode</code>)</td>
<td>Halts execution and returns the value of <code>exitCode</code> to the parent process. By convention, 0 indicates normal termination. All other values indicate some form of error.</td>
</tr>
<tr>
<td>long freeMemory()</td>
<td>Returns the approximate number of bytes of free memory available to the Java run-time system.</td>
</tr>
<tr>
<td>void gc()</td>
<td>Initiates garbage collection.</td>
</tr>
<tr>
<td>static Runtime getRuntime()</td>
<td>Returns the current <code>Runtime</code> object.</td>
</tr>
<tr>
<td>void halt(int <code>code</code>)</td>
<td>Immediately terminates the Java Virtual Machine. No termination threads or finalizers are run. The value of <code>code</code> is returned to the invoking process.</td>
</tr>
<tr>
<td>void load(String <code>libraryFileName</code>)</td>
<td>Loads the dynamic library whose file is specified by <code>libraryFileName</code>, which must specify its complete path.</td>
</tr>
<tr>
<td>void loadLibrary(String <code>libraryName</code>)</td>
<td>Loads the dynamic library whose name is associated with <code>libraryName</code>.</td>
</tr>
<tr>
<td>Boolean removeShutdownHook(Thread <code>thrd</code>)</td>
<td>Removes <code>thrd</code> from the list of threads to run when the Java Virtual Machine terminates. It returns <code>true</code> if successful—that is, if the thread was removed.</td>
</tr>
<tr>
<td>void runFinalization()</td>
<td>Initiates calls to the <code>finalize()</code> methods of unused but not yet recycled objects.</td>
</tr>
<tr>
<td>long totalMemory()</td>
<td>Returns the total number of bytes of memory available to the program.</td>
</tr>
<tr>
<td>static Runtime.Version version()</td>
<td>Returns the Java version being used. See <code>Runtime.Version</code> for details. (Added by JDK 9.)</td>
</tr>
</tbody>
</table>
Memory Management

Although Java provides automatic garbage collection, sometimes you will want to know how large the object heap is and how much of it is left. You can use this information, for example, to check your code for efficiency or to approximate how many more objects of a certain type can be instantiated. To obtain these values, use the **totalMemory()** and **freeMemory()** methods.

As mentioned in Part I, Java’s garbage collector runs periodically to recycle unused objects. However, sometimes you will want to collect discarded objects prior to the collector’s next appointed rounds. You can run the garbage collector on demand by calling the **gc()** method. A good thing to try is to call **gc()** and then call **freeMemory()** to get a baseline memory usage. Next, execute your code and call **freeMemory()** again to see how much memory it is allocating. The following program illustrates this idea:
// Demonstrate totalMemory(), freeMemory() and gc().

class MemoryDemo {
    public static void main(String args[]) {
        Runtime r = Runtime.getRuntime();
        long mem1, mem2;
        Integer someints[] = new Integer[1000];

        System.out.println("Total memory is: " +
            r.totalMemory());
        mem1 = r.freeMemory();
        System.out.println("Initial free memory: " + mem1);
        r.gc();
        mem1 = r.freeMemory();
        System.out.println("Free memory after garbage collection: "
            + mem1);

        for (int i = 0; i < 1000; i++)
            someints[i] = Integer.valueOf(i); // allocate integers

        mem2 = r.freeMemory();
        System.out.println("Free memory after allocation: "
            + mem2);
        System.out.println("Memory used by allocation: "
            + (mem1-mem2));

        // discard Integers
        for (int i = 0; i < 1000; i++) someints[i] = null;

        r.gc(); // request garbage collection

        mem2 = r.freeMemory();
        System.out.println("Free memory after collecting" +
            " discarded Integers: " + mem2);
    }
}

Sample output from this program is shown here (of course, your actual results may vary):
Executing Other Programs

In safe environments, you can use Java to execute other heavyweight processes (that is, programs) on your multitasking operating system. Several forms of the `exec()` method allow you to name the program you want to run as well as its input parameters. The `exec()` method returns a `Process` object, which can then be used to control how your Java program interacts with this new running process. Because Java can run on a variety of platforms and under a variety of operating systems, `exec()` is inherently environment-dependent.

The following example uses `exec()` to launch `notepad`, Windows’ simple text editor. Obviously, this example must be run under the Windows operating system.

```java
// Demonstrate exec().
class ExecDemo {
    public static void main(String args[]) {
        Runtime r = Runtime.getRuntime();
        Process p = null;

        try {
            p = r.exec("notepad");
        } catch (Exception e) {
            System.out.println("Error executing notepad.");
        }
    }
}
```

There are several alternative forms of `exec()`, but the one shown in the example is often sufficient. The `Process` object returned by `exec()` can be manipulated by `Process`’ methods after the new program starts running. You can kill the subprocess with the `destroy()` method. The `waitFor()` method causes your program to wait until the subprocess finishes. The `exitValue()` method returns the value returned by the subprocess when it is finished. This is typically 0 if no problems occur. Here is the preceding `exec()` example modified to wait for the running process to exit:
While a subprocess is running, you can write to and read from its standard input and output. The `getOutputStream()` and `getInputStream()` methods return the handles to standard in and out of the subprocess. (I/O is examined in detail in Chapter 21.)

### Runtime.Version

Added by JDK 9, `Runtime.Version` encapsulates version information pertaining to the Java environment. You can obtain an instance of `Runtime.Version` for the current platform by calling `Runtime.version()`.

Three key items (represented as integers) are included in the version information, in this order: major version number, minor version number, and security version number. (The security version number indicates the current security update.) In addition to these three elements, other optional information may be available.

You can obtain version information by using various methods defined by `Runtime.Version`. For example, you can obtain the major, minor, and security values by calling `major()`, `minor()`, and `security()`, respectively. Each is shown here:

```java
int major()
int minor()
int security()
```

Each returns an `int` value that represents the indicated value. The following program demonstrates their use:

```java
// Wait until notepad is terminated.
class ExecDemoFini {
    public static void main(String args[]) {
        Runtime r = Runtime.getRuntime();
        Process p = null;

        try {
            p = r.exec("notepad");
            p.waitFor();
        } catch (Exception e) {
            System.out.println("Error executing notepad.");
        }
        System.out.println("Notepad returned " + p.exitValue());
    }
}
```
In addition to the methods just shown, `Runtime.Version` has methods that obtain various pieces of optional data. For example, you can obtain the build number, if present, by calling `build()`. Pre-release information, if present, is returned by `pre()`. Other optional information may also be present and is obtained by calling `optional()`. You can compare versions by using `compareTo()` or `compareToIgnoreOptional()`. You can use `equals()` and `equalsIgnoreOptional()` to determine version equality. The `version()` method returns a list of the version numbers. You can convert a valid version string into a `Runtime.Version` object by calling `parse()`.

### ProcessBuilder

`ProcessBuilder` provides another way to start and manage processes (that is, programs). As explained earlier, all processes are represented by the `Process` class, and a process can be started by `Runtime.exec()`. `ProcessBuilder` offers more control over the processes. For example, you can set the current working directory.

`ProcessBuilder` defines these constructors:

```
ProcessBuilder(List<String> args)
ProcessBuilder(String ... args)
```

Here, `args` is a list of arguments that specify the name of the program to be executed along with any required command-line arguments. In the first constructor, the arguments are passed in a `List`. In the second, they are specified through a `varargs` parameter. Table 18-12 describes the methods defined by `ProcessBuilder`. 

```java
class VerDemo {
    public static void main(String args[]) {
        Runtime.Version ver = Runtime.version();

        // Display individual version numbers.
        System.out.println("Major version: " + ver.major());
        System.out.println("Minor version: " + ver.minor());
        System.out.println("Security version: " + ver.security());
    }
}
```
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>List&lt;String&gt; command()</td>
<td>Returns a reference to a List that contains the name of the program and its arguments. Changes to this list affect the invoking object.</td>
</tr>
<tr>
<td>ProcessBuilder command(List&lt;String&gt; args)</td>
<td>Sets the name of the program and its arguments to those specified by args. Changes to this list affect the invoking object. Returns a reference to the invoking object.</td>
</tr>
<tr>
<td>ProcessBuilder command(String... args)</td>
<td>Sets the name of the program and its arguments to those specified by args. Returns a reference to the invoking object.</td>
</tr>
<tr>
<td>File directory()</td>
<td>Returns the current working directory of the invoking object. This value will be null if the directory is the same as that of the Java program that started the process.</td>
</tr>
<tr>
<td>ProcessBuilder directory(File dir)</td>
<td>Sets the current working directory of the invoking object. Returns a reference to the invoking object.</td>
</tr>
<tr>
<td>Map&lt;String, String&gt; environment()</td>
<td>Returns the environmental variables associated with the invoking object as key/value pairs.</td>
</tr>
<tr>
<td>ProcessBuilder inheritIO()</td>
<td>Causes the invoked process to use the same source and target for the standard I/O streams as the invoking process.</td>
</tr>
<tr>
<td>ProcessBuilder redirectError(File f)</td>
<td>Sets the target for standard error to the specified file. Returns a reference to the invoking object.</td>
</tr>
<tr>
<td>boolean redirectErrorStream()</td>
<td>Returns true if the standard error stream has been redirected to the standard output stream. Returns false if the streams are separate.</td>
</tr>
<tr>
<td>ProcessBuilder redirectErrorStream(boolean merge)</td>
<td>If merge is true, then the standard error stream is redirected to standard output. If merge is false, the streams are separated, which is the default state. Returns a reference to the invoking object.</td>
</tr>
</tbody>
</table>
In Table 18-12, notice the methods that use the `ProcessBuilder.Redirect` class. This abstract class encapsulates an I/O source or target linked to a subprocess. Among other things, these methods enable you to redirect the source or target of I/O operations. For example, you can redirect to a file by calling `to()`), redirect from a file by calling `from()`, and append to a file by calling `appendTo()`. A `File` object linked to the file can be obtained by calling `file()`. These methods are shown here:

```
static ProcessBuilder.Redirect to(File f)
static ProcessBuilder.Redirect from(File f)
static ProcessBuilder.Redirect appendTo(File f)
File file()
```

Another method supported by `ProcessBuilder.Redirect` is `type()`, which returns a value of the enumeration type `ProcessBuilder.Redirect.Type`. This enumeration describes the type of the redirection. It defines these values: `APPEND`, `INHERIT`, `PIPE`, `READ`, or `WRITE`. `ProcessBuilder.Redirect` also defines the constants `INHERIT`, `PIPE`, and `DISCARD`.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>ProcessBuilder redirectInput(File f)</code></td>
<td>Sets the source for standard input to the specified file. Returns a reference to the invoking object.</td>
</tr>
<tr>
<td><code>ProcessBuilder redirectOutput(File f)</code></td>
<td>Sets the target for standard output to the specified file. Returns a reference to the invoking object.</td>
</tr>
<tr>
<td><code>Process start() throws IOException</code></td>
<td>Begins the process specified by the invoking object. In other words, it runs the specified program.</td>
</tr>
<tr>
<td><code>static List&lt;Process&gt; startPipeline(List&lt;ProcessBuilder&gt; pbList) throws IOException</code></td>
<td>Pipelines the processes in <code>pbList</code>. (Added by JDK 9.)</td>
</tr>
</tbody>
</table>

Table 18-12  The Methods Defined by `ProcessBuilder`
To create a process using `ProcessBuilder`, simply create an instance of `ProcessBuilder`, specifying the name of the program and any needed arguments. To begin execution of the program, call `start()` on that instance. Here is an example that executes the Windows text editor `notepad`. Notice that it specifies the name of the file to edit as an argument.

```java
class PBDemo {
    public static void main(String args[]) {
        try {
            ProcessBuilder proc =
                new ProcessBuilder("notepad.exe", "testfile");
            proc.start();
        } catch (Exception e) {
            System.out.println("Error executing notepad.");
        }
    }
}
```

**System**

The `System` class holds a collection of static methods and variables. The standard input, output, and error output of the Java run time are stored in the `in`, `out`, and `err` variables. The methods defined by `System` are shown in Table 18-13. Many of the methods throw a `SecurityException` if the operation is not permitted by the security manager.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>static void arraycopy(Object source, int sourceStart, Object target, int targetStart, int size)</code></td>
<td>Copies an array. The array to be copied is passed in <code>source</code>, and the index at which point the copy will begin within <code>source</code> is passed in <code>sourceStart</code>. The array that will receive the copy is passed in <code>target</code>, and the index at which point the copy will begin within <code>target</code> is passed in <code>targetStart</code>. <code>size</code> is the number of elements that are copied.</td>
</tr>
<tr>
<td><code>static String clearProperty(String which)</code></td>
<td>Deletes the environmental variable specified by <code>which</code>. The previous value associated with <code>which</code> is returned.</td>
</tr>
<tr>
<td><code>static Console console()</code></td>
<td>Returns the console associated with the JVM. <code>null</code> is returned if the JVM currently has no console.</td>
</tr>
<tr>
<td><code>static long currentTimeMillis()</code></td>
<td>Returns the current time in terms of milliseconds since midnight, January 1, 1970.</td>
</tr>
<tr>
<td><code>static void exit(int exitCode)</code></td>
<td>Halts execution and returns the value of <code>exitCode</code> to the parent process (usually the operating system). By convention, 0 indicates normal termination. All other values indicate some form of error.</td>
</tr>
<tr>
<td><code>static void gc()</code></td>
<td>Initiates garbage collection.</td>
</tr>
<tr>
<td><code>static Map&lt;String, String&gt; getenv()</code></td>
<td>Returns a <code>Map</code> that contains the current environmental variables and their values.</td>
</tr>
<tr>
<td><code>static String getenv(String which)</code></td>
<td>Returns the value associated with the environmental variable passed in <code>which</code>.</td>
</tr>
<tr>
<td><code>static System.Logger getLogger(String logName)</code></td>
<td>Returns a reference to an object that can be used for program logging. The name of the logger is passed in <code>logName</code>. (Added by JDK 9.)</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>static System.Logger getLogger(String logName, ResourceBundle rb)</td>
<td>Returns a reference to an object that can be used for program logging. The name of the logger is passed in logName. Localization is supported by the resource bundle passed in rb. (Added by JDK 9.)</td>
</tr>
<tr>
<td>static Properties getProperties()</td>
<td>Returns the properties associated with the Java runtime system. (The Properties class is described in Chapter 19.)</td>
</tr>
<tr>
<td>static String getProperty(String which)</td>
<td>Returns the property associated with which. A null object is returned if the desired property is not found.</td>
</tr>
<tr>
<td>static String getProperty(String which, String default)</td>
<td>Returns the property associated with which. If the desired property is not found, default is returned.</td>
</tr>
<tr>
<td>static SecurityManager getSecurityManager()</td>
<td>Returns the current security manager or a null object if no security manager is installed.</td>
</tr>
<tr>
<td>static int identityHashCode(Object obj)</td>
<td>Returns the identity hash code for obj.</td>
</tr>
<tr>
<td>static Channel inheritedChannel() throws IOException</td>
<td>Returns the channel inherited by the Java Virtual Machine. Returns null if no channel is inherited.</td>
</tr>
<tr>
<td>static String lineSeparator()</td>
<td>Returns a string that contains the line-separator characters.</td>
</tr>
<tr>
<td>static void load(String libraryFileName)</td>
<td>Loads the dynamic library whose file is specified by libraryFileName, which must specify its complete path.</td>
</tr>
<tr>
<td>static void loadLibrary(String libraryName)</td>
<td>Loads the dynamic library whose name is associated with libraryName.</td>
</tr>
<tr>
<td>static String mapLibraryName(String lib)</td>
<td>Returns a platform-specific name for the library named lib.</td>
</tr>
<tr>
<td>static long nanoTime()</td>
<td>Obtains the most precise timer in the system and returns its value in terms of nanoseconds since some arbitrary starting point. The accuracy of the timer is unknowable.</td>
</tr>
<tr>
<td>static void runFinalization()</td>
<td>Initiates calls to the finalize() methods of unused but not yet recycled objects.</td>
</tr>
<tr>
<td>static void setErr(OutputStream eStream)</td>
<td>Sets the standard err stream to eStream.</td>
</tr>
<tr>
<td>static void setIn(InputStream iStream)</td>
<td>Sets the standard in stream to iStream.</td>
</tr>
<tr>
<td>static void setOut(OutputStream oStream)</td>
<td>Sets the standard out stream to oStream.</td>
</tr>
<tr>
<td>static void setProperties(Properties sysProperties)</td>
<td>Sets the current system properties as specified by sysProperties.</td>
</tr>
<tr>
<td>static String setProperty(String which, String v)</td>
<td>Assigns the value v to the property named which.</td>
</tr>
<tr>
<td>static void setSecurityManager(SecurityManager secMan)</td>
<td>Sets the security manager to that specified by secMan.</td>
</tr>
</tbody>
</table>
Using `currentTimeMillis()` to Time Program Execution

One use of the `System` class that you might find particularly interesting is to use the `currentTimeMillis()` method to time how long various parts of your program take to execute. The `currentTimeMillis()` method returns the current time in terms of milliseconds since midnight, January 1, 1970. To time a section of your program, store this value just before beginning the section in question. Immediately upon completion, call `currentTimeMillis()` again. The elapsed time will be the ending time minus the starting time. The following program demonstrates this:

```java
// Timing program execution.

class Elapsed {
    public static void main(String args[]) {
        long start, end;

        System.out.println("Timing a for loop from 0 to 100,000,000");

        // time a for loop from 0 to 100,000,000
        start = System.currentTimeMillis(); // get starting time
        for (long i=0; i < 100000000L; i++) {
            end = System.currentTimeMillis(); // get ending time
            System.out.println("Elapsed time: "+ (end-start));
    }
}

Here is a sample run (remember that your results probably will differ):

Timing a for loop from 0 to 100,000,000
Elapsed time: 10

If your system has a timer that offers nanosecond precision, then you could rewrite the preceding program to use `nanoTime()` rather than `currentTimeMillis()`. For example, here is the key portion of the program rewritten to use `nanoTime()`:
Using arraycopy()

The `arraycopy()` method can be used to copy quickly an array of any type from one place to another. This is much faster than the equivalent loop written out longhand in Java. Here is an example of two arrays being copied by the `arraycopy()` method. First, `a` is copied to `b`. Next, all of `a`’s elements are shifted down by one. Then, `b` is shifted up by one.

```java
// Using arraycopy().

class ACDemo {
    static byte a[] = { 65, 66, 67, 68, 69, 70, 71, 72, 73, 74 };  
    static byte b[] = { 77, 77, 77, 77, 77, 77, 77, 77, 77, 77 };  

    public static void main(String args[]) {
        System.out.println("a = " + new String(a));
        System.out.println("b = " + new String(b));
        System.arraycopy(a, 0, b, 0, a.length);
        System.out.println("a = " + new String(a));
        System.out.println("b = " + new String(b));
        System.arraycopy(a, 0, a, 1, a.length - 1);
        System.arraycopy(b, 1, b, 0, b.length - 1);
        System.out.println("a = " + new String(a));
        System.out.println("b = " + new String(b));
    }
}

As you can see from the following output, you can copy using the same source and destination in either direction:

a = ABCDEFGHIJ
b = MMMMMMMMMMM
a = ABCDEFGHIJ
b = ABCDEFGHIJ
a = AABCDGHI
b = BCDEFGHI

Environment Properties

The following properties are available in all cases:
You can obtain the values of various environment variables by calling the `System.getProperty()` method. For example, the following program displays the path to the current user directory:

```java
class ShowUserDir {
    public static void main(String args[]) {
        System.out.println(System.getProperty("user.dir"));
    }
}
```

**System.Logger and System.LoggerFinder**

Added by JDK 9, the `System.Logger` interface and `System.LoggerFinder` class support a program log. A logger can be found by use of `System.getLogger()`. `System.Logger` provides the interface to the logger.

**Object**

As mentioned in Part I, `Object` is a superclass of all other classes. `Object` defines the methods shown in Table 18-14, which are available to every object.
Table 18-14  The Methods Defined by Object

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object clone() throws CloneNotSupportedException</td>
<td>Creates a new object that is the same as the invoking object.</td>
</tr>
<tr>
<td>boolean equals(Object object)</td>
<td>Returns true if the invoking object is equivalent to object.</td>
</tr>
<tr>
<td>void finalize() throws Throwable</td>
<td>Default finalize() method. It is called before an unused object is recycled. (Deprecated by JDK 9.)</td>
</tr>
<tr>
<td>final Class&lt;?&gt; getClass()</td>
<td>Obtains a Class object that describes the invoking object.</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns the hash code associated with the invoking object.</td>
</tr>
<tr>
<td>final void notify()</td>
<td>Notifies a thread waiting on the invoking object.</td>
</tr>
<tr>
<td>final void notifyAll()</td>
<td>Notifies all threads waiting on the invoking object.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Returns a string that describes the object.</td>
</tr>
<tr>
<td>final void wait()</td>
<td>Waits on another thread of execution.</td>
</tr>
<tr>
<td></td>
<td>throws InterruptedException</td>
</tr>
<tr>
<td>final void wait(long milliseconds) throws InterruptedException</td>
<td>Waits up to the specified number of milliseconds on another thread of execution.</td>
</tr>
<tr>
<td>final void wait(long milliseconds, int nanoseconds) throws InterruptedException</td>
<td>Waits up to the specified number of milliseconds plus nanoseconds on another thread of execution.</td>
</tr>
</tbody>
</table>

**Using clone( ) and the Cloneable Interface**

Most of the methods defined by Object are discussed elsewhere in this book. However, one deserves special attention: clone( ). The clone( ) method generates a duplicate copy of the object on which it is called. Only classes that implement the Cloneable interface can be cloned.

The Cloneable interface defines no members. It is used to indicate that a class allows an exact copy of an object (that is, a clone) to be made. If you try to call clone( ) on a class that does not implement Cloneable, a CloneNotSupportedException is thrown. When a clone is made, the constructor for the object being cloned is not called. As implemented by Object, a clone is simply an exact copy of the original.

Cloning is a potentially dangerous action, because it can cause unintended side
effects. For example, if the object being cloned contains a reference variable called \texttt{obRef}, then when the clone is made, \texttt{obRef} in the clone will refer to the same object as does \texttt{obRef} in the original. If the clone makes a change to the contents of the object referred to by \texttt{obRef}, then it will be changed for the original object, too. Here is another example: If an object opens an I/O stream and is then cloned, two objects will be capable of operating on the same stream. Further, if one of these objects closes the stream, the other object might still attempt to write to it, causing an error. In some cases, you will need to override the \texttt{clone()} method defined by \texttt{Object} to handle these types of problems.

Because cloning can cause problems, \texttt{clone()} is declared as \texttt{protected} inside \texttt{Object}. This means that it must either be called from within a method defined by the class that implements \texttt{Cloneable}, or it must be explicitly overridden by that class so that it is public. Let’s look at an example of each approach.

The following program implements \texttt{Cloneable} and defines the method \texttt{cloneTest()}, which calls \texttt{clone()} in \texttt{Object}:
// Demonstrate the clone() method

class TestClone implements Cloneable {
    int a;
    double b;

    // This method calls Object's clone().
    TestClone cloneTest() {
        try {
            // call clone in Object.
            return (TestClone) super.clone();
        } catch(CloneNotSupportedException e) {
            System.out.println("Cloning not allowed.");
            return this;
        }
    }
}

class CloneDemo {
    public static void main(String args[]) {
        TestClone x1 = new TestClone();
        TestClone x2;

        x1.a = 10;
        x1.b = 20.98;

        x2 = x1.cloneTest(); // clone x1

        System.out.println("x1: " + x1.a + " " + x1.b);
        System.out.println("x2: " + x2.a + " " + x2.b);
    }
}

Here, the method cloneTest() calls clone() in Object and returns the result. Notice that the object returned by clone() must be cast into its appropriate type (TestClone).

The following example overrides clone() so that it can be called from code outside of its class. To do this, its access specifier must be public, as shown here:
The side effects caused by cloning are sometimes difficult to see at first. It is easy to think that a class is safe for cloning when it actually is not. In general, you should not implement `Cloneable` for any class without good reason.

**Class**

`Class` encapsulates the run-time state of a class or interface. Objects of type `Class` are created automatically, when classes are loaded. You cannot explicitly declare a `Class` object. Generally, you obtain a `Class` object by calling the `getClass()` method.
defined by **Object.** **Class** is a generic type that is declared as shown here:

```java
class Class<T>
```

Here, `T` is the type of the class or interface represented. A sampling of methods defined by **Class** is shown in Table 18-15. In the table, notice the `getModule()` method. It is part of the support for the new modules feature added by JDK 9.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static Class&lt;?&gt; forName(Module mod, String name)</td>
<td>Returns a Class object corresponding to its complete name and the module in which it resides. (Added by JDK 9.)</td>
</tr>
<tr>
<td>static Class&lt;?&gt; forName(String name) throws ClassNotFoundException</td>
<td>Returns a Class object given its complete name.</td>
</tr>
<tr>
<td>static Class&lt;?&gt; forName(String name, boolean how, ClassLoader ldr) throws ClassNotFoundException</td>
<td>Returns a Class object given its complete name. The object is loaded using the loader specified by ldr. If how is true, the object is initialized; otherwise, it is not.</td>
</tr>
<tr>
<td>&lt;A extends Annotation&gt; A getAnnotation(Class&lt;A&gt; annoType)</td>
<td>Returns an Annotation object that contains the annotation associated with annoType for the invoking object.</td>
</tr>
<tr>
<td>Annotation[] getAnnotations()</td>
<td>Obtains all annotations associated with the invoking object and stores them in an array of Annotation objects. Returns a reference to this array.</td>
</tr>
<tr>
<td>&lt;A extends Annotation&gt; A[] getAnnotationsByType(Class&lt;A&gt; annoType)</td>
<td>Returns an array of the annotations (including repeated annotations) of annoType associated with the invoking object.</td>
</tr>
<tr>
<td>Class&lt;?&gt;[] getClasses()</td>
<td>Returns a Class object for each public class and interface that is a member of the class represented by the invoking object.</td>
</tr>
<tr>
<td>ClassLoader getClassLoader()</td>
<td>Returns the ClassLoader object that loaded the class or interface.</td>
</tr>
<tr>
<td>Constructor&lt;T&gt; getConstructor(Class&lt;?&gt;... paramTypes) throws NoSuchMethodException, SecurityException</td>
<td>Returns a Constructor object that represents the constructor for the class represented by the invoking object that has the parameter types specified by paramTypes.</td>
</tr>
<tr>
<td>Constructor&lt;?&gt;[] getConstructors() throws SecurityException</td>
<td>Obtains a Constructor object for each public constructor of the class represented by the invoking object and stores them in an array. Returns a reference to this array.</td>
</tr>
<tr>
<td>Annotation[] getDeclaredAnnotations()</td>
<td>Obtains an Annotation object for all the annotations that are declared by the invoking object and stores them in an array. Returns a reference to this array. (Inherited annotations are ignored.)</td>
</tr>
<tr>
<td>&lt;A extends Annotation&gt; A[] getDeclaredAnnotationsByType(Class&lt;A&gt; annoType)</td>
<td>Returns an array of the non-inherited annotations (including repeated annotations) of annoType associated with the invoking object.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><code>Constructor&lt;?&gt;[] getDeclaredConstructors()</code></td>
<td>Obtains a <code>Constructor</code> object for each constructor declared by the class represented by the invoking object and stores them in an array. Returns a reference to this array. (Superclass constructors are ignored.)</td>
</tr>
<tr>
<td><code>Field[] getDeclaredFields()</code></td>
<td>Obtains a <code>Field</code> object for each field declared by the class or interface represented by the invoking object and stores them in an array. Returns a reference to this array. (Inherited fields are ignored.)</td>
</tr>
<tr>
<td><code>Method[] getDeclaredMethods()</code></td>
<td>Obtains a <code>Method</code> object for each method declared by the class or interface represented by the invoking object and stores them in an array. Returns a reference to this array. (Inherited methods are ignored.)</td>
</tr>
<tr>
<td><code>Field getField(String fieldName) throws NoSuchMethodException, SecurityException</code></td>
<td>Returns a <code>Field</code> object that represents the public field specified by <code>fieldName</code> for the class or interface represented by the invoking object.</td>
</tr>
<tr>
<td><code>Field[] getFields()</code></td>
<td>Obtains a <code>Field</code> object for each public field of the class or interface represented by the invoking object and stores them in an array. Returns a reference to this array.</td>
</tr>
<tr>
<td><code>Class&lt;?&gt;[] getInterfaces()</code></td>
<td>When invoked on an object that represents a class, this method returns an array of the interfaces implemented by that class. When invoked on an object that represents an interface, this method returns an array of interfaces extended by that interface.</td>
</tr>
<tr>
<td><code>Method getMethod(String methName, Class&lt;?&gt; ... paramTypes) throws NoSuchMethodException, SecurityException</code></td>
<td>Returns a <code>Method</code> object that represents the public method specified by <code>methName</code> and having the parameter types specified by <code>paramTypes</code> in the class or interface represented by the invoking object.</td>
</tr>
<tr>
<td><code>Method[] getMethods()</code></td>
<td>Obtains a <code>Method</code> object for each public method of the class or interface represented by the invoking object and stores them in an array. Returns a reference to this array.</td>
</tr>
<tr>
<td><code>Module getModule()</code></td>
<td>Returns a <code>Module</code> object that represents the module in which the invoking class type resides. (Added by JDK 9.)</td>
</tr>
<tr>
<td><code>String getName()</code></td>
<td>Returns the complete name of the class or interface of the type represented by the invoking object.</td>
</tr>
<tr>
<td><code>String getPackageName()</code></td>
<td>Returns the name of the package of which the invoking class type is a part. (Added by JDK 9.)</td>
</tr>
<tr>
<td><code>ProtectionDomain getProtectionDomain()</code></td>
<td>Returns the protection domain associated with the invoking object.</td>
</tr>
<tr>
<td><code>Class&lt;?&gt; super T&gt; getSuperclass()</code></td>
<td>Returns the superclass of the type represented by the invoking object. The return value is <code>null</code> if the represented type is <code>Object</code> or not a class.</td>
</tr>
<tr>
<td><code>boolean isInterface()</code></td>
<td>Returns <code>true</code> if the type represented by the invoking object is an interface. Otherwise, it returns <code>false</code>.</td>
</tr>
<tr>
<td><code>String toString()</code></td>
<td>Returns the string representation of the type represented by the invoking object or interface.</td>
</tr>
</tbody>
</table>
Table 18-15  A Sampling of Methods Defined by Class

The methods defined by Class are often useful in situations where run-time type information about an object is required. As Table 18-15 shows, methods are provided that allow you to determine additional information about a particular class, such as its public constructors, fields, and methods. Among other things, this is important for the Java Beans functionality, which is discussed later in this book.

The following program demonstrates getClass() (inherited from Object) and getSuperclass() (from Class):

```java
// Demonstrate Run-Time Type Information.

class X {
    int a;
    float b;
}

class Y extends X {
    double c;
}

class RTTI {
    public static void main(String args[]) {
        X x = new X();
        Y y = new Y();
        Class<?> c1Obj;

        c1Obj = x.getClass(); // get Class reference
        System.out.println("x is object of type: " + c1Obj.getName());

        c1Obj = y.getClass(); // get Class reference
        System.out.println("y is object of type: " + c1Obj.getName());
        c1Obj = c1Obj.getSuperclass();
        System.out.println("y's superclass is " + c1Obj.getName());
    }
}
```

The output from this program is shown here:
ClassLoader

The abstract class `ClassLoader` defines how classes are loaded. Your application can create subclasses that extend `ClassLoader`, implementing its methods. Doing so allows you to load classes in some way other than the way they are normally loaded by the Java run-time system. However, this is not something that you will normally need to do.

Math

The `Math` class contains all the floating-point functions that are used for geometry and trigonometry, as well as several general-purpose methods. `Math` defines two `double` constants: E (approximately 2.72) and PI (approximately 3.14).

Trigonometric Functions

The following methods accept a `double` parameter for an angle in radians and return the result of their respective trigonometric function:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static double sin(double arg)</td>
<td>Returns the sine of the angle specified by <code>arg</code> in radians.</td>
</tr>
<tr>
<td>static double cos(double arg)</td>
<td>Returns the cosine of the angle specified by <code>arg</code> in radians.</td>
</tr>
<tr>
<td>static double tan(double arg)</td>
<td>Returns the tangent of the angle specified by <code>arg</code> in radians.</td>
</tr>
</tbody>
</table>

The next methods take as a parameter the result of a trigonometric function and return, in radians, the angle that would produce that result. They are the inverse of their non-arc companions:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static double asin(double arg)</td>
<td>Returns the angle whose sine is specified by <code>arg</code>.</td>
</tr>
<tr>
<td>static double acos(double arg)</td>
<td>Returns the angle whose cosine is specified by <code>arg</code>.</td>
</tr>
<tr>
<td>static double atan(double arg)</td>
<td>Returns the angle whose tangent is specified by <code>arg</code>.</td>
</tr>
<tr>
<td>static double atan2(double x, double y)</td>
<td>Returns the angle whose tangent is <code>x/y</code>.</td>
</tr>
</tbody>
</table>
The next methods compute the hyperbolic sine, cosine, and tangent of an angle:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static double sinh(arg)</td>
<td>Returns the hyperbolic sine of the angle specified by arg.</td>
</tr>
<tr>
<td>static double cosh(arg)</td>
<td>Returns the hyperbolic cosine of the angle specified by arg.</td>
</tr>
<tr>
<td>static double tanh(arg)</td>
<td>Returns the hyperbolic tangent of the angle specified by arg.</td>
</tr>
</tbody>
</table>

**Exponential Functions**

*Math* defines the following exponential methods:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static double cbrt(arg)</td>
<td>Returns the cube root of arg.</td>
</tr>
<tr>
<td>static double exp(arg)</td>
<td>Returns e to the arg.</td>
</tr>
<tr>
<td>static double expm1(arg)</td>
<td>Returns e to the arg−1.</td>
</tr>
<tr>
<td>static double log(arg)</td>
<td>Returns the natural logarithm of arg.</td>
</tr>
<tr>
<td>static double log10(arg)</td>
<td>Returns the base 10 logarithm for arg.</td>
</tr>
<tr>
<td>static double log1p(arg)</td>
<td>Returns the natural logarithm for arg + 1.</td>
</tr>
<tr>
<td>static double pow(arg, x)</td>
<td>Returns y raised to the x; for example, pow(2.0, 3.0) returns 8.0.</td>
</tr>
<tr>
<td>static double scalb(arg, factor)</td>
<td>Returns arg × 2(^{\text{factor}}).</td>
</tr>
<tr>
<td>static float scalb(arg, factor)</td>
<td>Returns arg × 2(^{\text{factor}}).</td>
</tr>
<tr>
<td>static double sqrt(arg)</td>
<td>Returns the square root of arg.</td>
</tr>
</tbody>
</table>

**Rounding Functions**

The *Math* class defines several methods that provide various types of rounding operations. They are shown in Table 18-16. Notice the two *ulp()* methods at the end of the table. In this context, *ulp* stands for *units in the last place*. It indicates the distance between a value and the next higher value. It can be used to help assess the accuracy of a result.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static int abs(int arg)</td>
<td>Returns the absolute value of arg.</td>
</tr>
<tr>
<td>static long abs(long arg)</td>
<td>Returns the absolute value of arg.</td>
</tr>
<tr>
<td>static float abs(float arg)</td>
<td>Returns the absolute value of arg.</td>
</tr>
<tr>
<td>static double abs(double arg)</td>
<td>Returns the absolute value of arg.</td>
</tr>
<tr>
<td>static double ceil(double arg)</td>
<td>Returns the smallest whole number greater than or equal to arg.</td>
</tr>
<tr>
<td>static double floor(double arg)</td>
<td>Returns the largest whole number less than or equal to arg.</td>
</tr>
<tr>
<td>static int floorDiv(int dividend, int divisor)</td>
<td>Returns the floor of the result of dividend/divisor.</td>
</tr>
<tr>
<td>static long floorDiv(long dividend, int divisor)</td>
<td>Returns the floor of the result of dividend/divisor.</td>
</tr>
<tr>
<td>static long floorDiv(long dividend, long divisor)</td>
<td>Returns the floor of the result of dividend/divisor.</td>
</tr>
<tr>
<td>static int floorMod(int dividend, int divisor)</td>
<td>Returns the floor of the remainder of dividend/divisor.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><code>static int floorMod(long dividend, int divisor)</code></td>
<td>Returns the floor of the remainder of <code>dividend/divisor</code>. (Added by JDK 9.)</td>
</tr>
<tr>
<td><code>static long floorMod(long dividend, long divisor)</code></td>
<td>Returns the floor of the remainder of <code>dividend/divisor</code>.</td>
</tr>
<tr>
<td><code>static int max(int x, int y)</code></td>
<td>Returns the maximum of <code>x</code> and <code>y</code>.</td>
</tr>
<tr>
<td><code>static long max(long x, long y)</code></td>
<td>Returns the maximum of <code>x</code> and <code>y</code>.</td>
</tr>
<tr>
<td><code>static float max(float x, float y)</code></td>
<td>Returns the maximum of <code>x</code> and <code>y</code>.</td>
</tr>
<tr>
<td><code>static double max(double x, double y)</code></td>
<td>Returns the maximum of <code>x</code> and <code>y</code>.</td>
</tr>
<tr>
<td><code>static int min(int x, int y)</code></td>
<td>Returns the minimum of <code>x</code> and <code>y</code>.</td>
</tr>
<tr>
<td><code>static long min(long x, long y)</code></td>
<td>Returns the minimum of <code>x</code> and <code>y</code>.</td>
</tr>
<tr>
<td><code>static float min(float x, float y)</code></td>
<td>Returns the minimum of <code>x</code> and <code>y</code>.</td>
</tr>
<tr>
<td><code>static double min(double x, double y)</code></td>
<td>Returns the minimum of <code>x</code> and <code>y</code>.</td>
</tr>
<tr>
<td><code>static double nextAfter(double arg, double toward)</code></td>
<td>Beginning with the value of <code>arg</code>, returns the next value in the direction of <code>toward</code>. If <code>arg</code> == <code>toward</code>, then <code>toward</code> is returned.</td>
</tr>
<tr>
<td><code>static float nextAfter(float arg, double toward)</code></td>
<td>Beginning with the value of <code>arg</code>, returns the next value in the direction of <code>toward</code>. If <code>arg</code> == <code>toward</code>, then <code>toward</code> is returned.</td>
</tr>
<tr>
<td><code>static double nextDown(double val)</code></td>
<td>Returns the next value lower than <code>val</code>.</td>
</tr>
<tr>
<td><code>static float nextDown(float val)</code></td>
<td>Returns the next value lower than <code>val</code>.</td>
</tr>
<tr>
<td><code>static double nextUp(double arg)</code></td>
<td>Returns the next value in the positive direction from <code>arg</code>.</td>
</tr>
<tr>
<td><code>static float nextUp(float arg)</code></td>
<td>Returns the next value in the positive direction from <code>arg</code>.</td>
</tr>
<tr>
<td><code>static double rint(double arg)</code></td>
<td>Returns the integer nearest in value to <code>arg</code>.</td>
</tr>
<tr>
<td><code>static int round(float arg)</code></td>
<td>Returns <code>arg</code> rounded up to the nearest <code>int</code>.</td>
</tr>
<tr>
<td><code>static long round(double arg)</code></td>
<td>Returns <code>arg</code> rounded up to the nearest <code>long</code>.</td>
</tr>
<tr>
<td><code>static float ulp(float arg)</code></td>
<td>Returns the ulp for <code>arg</code>.</td>
</tr>
<tr>
<td><code>static double ulp(double arg)</code></td>
<td>Returns the ulp for <code>arg</code>.</td>
</tr>
</tbody>
</table>

Table 18-16  The Rounding Methods Defined by Math

Miscellaneous Math Methods
In addition to the methods just shown, Math defines several other methods, which are shown in Table 18-17. Notice that several of the methods use the suffix Exact. They throw an ArithmeticException if overflow occurs. Thus, these methods give you an easy way to watch various operations for overflow.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static int addExact(int arg1, int arg2)</td>
<td>Returns arg1 + arg2. Throws an ArithmeticException if overflow occurs.</td>
</tr>
<tr>
<td>static long addExact(long arg1, long arg2)</td>
<td>Returns arg1 + arg2. Throws an ArithmeticException if overflow occurs.</td>
</tr>
<tr>
<td>static double copySign(double arg, double signarg)</td>
<td>Returns arg with same sign as that of signarg.</td>
</tr>
<tr>
<td>static float copySign(float arg, float signarg)</td>
<td>Returns arg with same sign as that of signarg.</td>
</tr>
<tr>
<td>static int decrementExact(int arg)</td>
<td>Returns arg – 1. Throws an ArithmeticException if overflow occurs.</td>
</tr>
<tr>
<td>static long decrementExact(long arg)</td>
<td>Returns arg – 1. Throws an ArithmeticException if overflow occurs.</td>
</tr>
<tr>
<td>static double fma(double arg1, double arg2, double arg3)</td>
<td>Adds arg3 to the product of arg1 and arg2 and returns the rounded result. The name is short for fused multiply add. (Added by JDK 9)</td>
</tr>
<tr>
<td>static float fma(float arg1, float arg2, float arg3)</td>
<td>Adds arg3 to the product of arg1 and arg2 and returns the rounded result. The name is short for fused multiply add. (Added by JDK 9)</td>
</tr>
<tr>
<td>static int getExponent(double arg)</td>
<td>Returns the base-2 exponent used by the binary representation of arg.</td>
</tr>
<tr>
<td>static int getExponent(float arg)</td>
<td>Returns the base-2 exponent used by the binary representation of arg.</td>
</tr>
<tr>
<td>static hypot(double side1, double side2)</td>
<td>Returns the length of the hypotenuse of a right triangle given the length of the two opposing sides.</td>
</tr>
<tr>
<td>static double IEEEremainder(double dividend, double divisor)</td>
<td>Returns the remainder of dividend / divisor.</td>
</tr>
<tr>
<td>static int incrementExact(int arg)</td>
<td>Returns arg + 1. Throws an ArithmeticException if overflow occurs.</td>
</tr>
<tr>
<td>static long incrementExact(long arg)</td>
<td>Returns arg + 1. Throws an ArithmeticException if overflow occurs.</td>
</tr>
<tr>
<td>static int multiplyExact(int arg1, int arg2)</td>
<td>Returns arg1 * arg2. Throws an ArithmeticException if overflow occurs.</td>
</tr>
<tr>
<td>static long multiplyExact(long arg1, int arg2)</td>
<td>Returns arg1 * arg2. Throws an ArithmeticException if overflow occurs. (Added by JDK 9)</td>
</tr>
<tr>
<td>static long multiplyExact(long arg1, long arg2)</td>
<td>Returns arg1 * arg2. Throws an ArithmeticException if overflow occurs.</td>
</tr>
<tr>
<td>static long multiplyFull(int arg1, int arg2)</td>
<td>Returns arg1 * arg2 as a long value. (Added by JDK 9)</td>
</tr>
<tr>
<td>static long multiplyHigh(long arg1, long arg2)</td>
<td>Returns a long value that contains the most significant bits of arg1 * arg2. (Added by JDK 9)</td>
</tr>
<tr>
<td>static int negateExact(int arg)</td>
<td>Returns –arg. Throws an ArithmeticException if overflow occurs.</td>
</tr>
<tr>
<td>static long negateExact(long arg)</td>
<td>Returns –arg. Throws an ArithmeticException if overflow occurs.</td>
</tr>
<tr>
<td>static double random()</td>
<td>Returns a pseudorandom number between 0 and 1.</td>
</tr>
<tr>
<td>static float signum(double arg)</td>
<td>Determines the sign of a value. It returns 0 if arg is 0, 1 if arg is greater than 0, and –1 if arg is less than 0.</td>
</tr>
<tr>
<td>static float signum(float arg)</td>
<td>Determines the sign of a value. It returns 0 if arg is 0, 1 if arg is greater than 0, and –1 if arg is less than 0.</td>
</tr>
<tr>
<td>static int subtractExact(int arg1, int arg2)</td>
<td>Returns arg1 – arg2. Throws an ArithmeticException if overflow occurs.</td>
</tr>
<tr>
<td>static long subtractExact(long arg1, long arg2)</td>
<td>Returns arg1 – arg2. Throws an ArithmeticException if overflow occurs.</td>
</tr>
<tr>
<td>static double toDegrees(double angle)</td>
<td>Converts radians to degrees. The angle passed to angle must be specified in radians. The result in degrees is returned.</td>
</tr>
<tr>
<td>static int toIntExact(long arg)</td>
<td>Returns arg as an int. Throws an ArithmeticException if overflow occurs.</td>
</tr>
<tr>
<td>static double toRadians(double angle)</td>
<td>Converts degrees to radians. The angle passed to angle must be specified in degrees. The result in radians is returned.</td>
</tr>
</tbody>
</table>
Table 18-17  Other Methods Defined by Math

The following program demonstrates `toRadians()` and `toDegrees()`:

```java
// Demonstrate toDegrees() and toRadians().
class Angles {
    public static void main(String args[]) {
        double theta = 120.0;

        System.out.println(theta + " degrees is " +
                            Math.toRadians(theta) + " radians.");

        theta = 1.312;
        System.out.println(theta + " radians is " +
                            Math.toDegrees(theta) + " degrees.");
    }
}
```

The output is shown here:

```
120.0 degrees is 2.0943951023931953 radians.
1.312 radians is 75.17206272116401 degrees.
```

**StrictMath**

The **StrictMath** class defines a complete set of mathematical methods that parallel those in **Math**. The difference is that the **StrictMath** version is guaranteed to generate precisely identical results across all Java implementations, whereas the methods in **Math** are given more latitude in order to improve performance.

**Compiler**

The **Compiler** class supports the creation of Java environments in which Java bytecode is compiled into executable code rather than interpreted. It is not for normal programming use and has been deprecated by JDK 9.

**Thread, ThreadGroup, and Runnable**

The **Runnable** interface and the **Thread** and **ThreadGroup** classes support multithreaded programming. Each is examined next.
NOTE An overview of the techniques used to manage threads, implement the Runnable interface, and create multithreaded programs is presented in Chapter 11.

The Runnable Interface

The Runnable interface must be implemented by any class that will initiate a separate thread of execution. Runnable only defines one abstract method, called run(), which is the entry point to the thread. It is defined like this:

```java
void run()
```

Threads that you create must implement this method.

Thread

Thread creates a new thread of execution. It implements Runnable and defines a number of constructors. Several are shown here:

```java
Thread( )
Thread(Runnable threadOb)
Thread(Runnable threadOb, String threadName)
Thread(String threadName)
Thread(ThreadGroup groupOb, Runnable threadOb)
Thread(ThreadGroup groupOb, Runnable threadOb, String threadName)
Thread(ThreadGroup groupOb, String threadName)
```

threadOb is an instance of a class that implements the Runnable interface and defines where execution of the thread will begin. The name of the thread is specified by threadName. When a name is not specified, one is created by the Java Virtual Machine. groupOb specifies the thread group to which the new thread will belong. When no thread group is specified, by default the new thread belongs to the same group as the parent thread.

The following constants are defined by Thread:

- MAX_PRIORITY
- MIN_PRIORITY
- NORM_PRIORITY

As expected, these constants specify the maximum, minimum, and default thread priorities.
The methods defined by `Thread` are shown in Table 18-18. In early versions of Java, `Thread` also included the methods `stop()`, `suspend()`, and `resume()`. However, as explained in Chapter 11, these were deprecated because they were inherently unstable. Also deprecated are `countStackFrames()`, because it calls `suspend()`, and `destroy()`, because it can cause deadlock.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static int activeCount()</td>
<td>Returns the approximate number of active threads in the group to which the thread belongs.</td>
</tr>
<tr>
<td>final void checkAccess()</td>
<td>Causes the security manager to verify that the current thread can access and/or change the thread on which <code>checkAccess()</code> is called.</td>
</tr>
<tr>
<td>static Thread currentThread()</td>
<td>Returns a <code>Thread</code> object that encapsulates the thread that calls this method.</td>
</tr>
<tr>
<td>static void dumpStack()</td>
<td>Displays the call stack for the thread.</td>
</tr>
<tr>
<td>static int enumerate(Thread threads[])</td>
<td>Puts copies of all <code>Thread</code> objects in the current thread's group into <code>threads</code>. The number of threads is returned.</td>
</tr>
<tr>
<td>static Map&lt;Thread, StackTraceElement[]&gt;</td>
<td>Returns a <code>Map</code> that contains the stack traces for all active threads. In the map, each entry consists of a key, which is the <code>Thread</code> object, and its value, which is an array of <code>StackTraceElement</code>.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>ClassLoader getContextClassLoader()</td>
<td>Returns the context class loader that is used to load classes and resources for this thread.</td>
</tr>
<tr>
<td>static Thread.UncaughtExceptionHandlergetDefaultUncaughtExceptionHandler()</td>
<td>Returns the default uncaught exception handler.</td>
</tr>
<tr>
<td>long getID()</td>
<td>Returns the ID of the invoking thread.</td>
</tr>
<tr>
<td>final String getName()</td>
<td>Returns the thread's name.</td>
</tr>
<tr>
<td>final int getPriority()</td>
<td>Returns the thread's priority setting.</td>
</tr>
<tr>
<td>StackTraceElement[] getStackTrace()</td>
<td>Returns an array containing the stack trace for the invoking thread.</td>
</tr>
<tr>
<td>Thread.State getState()</td>
<td>Returns the invoking thread's state.</td>
</tr>
<tr>
<td>final ThreadGroup getThreadGroup()</td>
<td>Returns the ThreadGroup object of which the invoking thread is a member.</td>
</tr>
<tr>
<td>Thread.UncaughtExceptionHandler getUncaughtExceptionHandler()</td>
<td>Returns the invoking thread's uncaught exception handler.</td>
</tr>
<tr>
<td>static boolean holdsLock(Object ob)</td>
<td>Returns true if the invoking thread owns the lock on ob. Returns false otherwise.</td>
</tr>
<tr>
<td>void interrupt()</td>
<td>Interrupts the thread.</td>
</tr>
<tr>
<td>static boolean interrupted()</td>
<td>Returns true if the currently executing thread has been interrupted. Otherwise, it returns false.</td>
</tr>
<tr>
<td>final boolean isAlive()</td>
<td>Returns true if the thread is still active. Otherwise, it returns false.</td>
</tr>
<tr>
<td>final boolean isDaemon()</td>
<td>Returns true if the thread is a daemon thread. Otherwise, it returns false.</td>
</tr>
<tr>
<td>boolean isInterrupted()</td>
<td>Returns true if the invoking thread has been interrupted. Otherwise, it returns false.</td>
</tr>
<tr>
<td>final void join()</td>
<td>Waits until the thread terminates.</td>
</tr>
<tr>
<td>throws InterruptedException</td>
<td></td>
</tr>
<tr>
<td>final void join(long milliseconds) throws InterruptedException</td>
<td>Waits up to the specified number of milliseconds for the thread on which it is called to terminate.</td>
</tr>
<tr>
<td>final void join(long milliseconds, int nanoseconds) throws InterruptedException</td>
<td>Waits up to the specified number of milliseconds plus nanoseconds for the thread on which it is called to terminate.</td>
</tr>
<tr>
<td>static void onSpinWait()</td>
<td>Called to signify that execution is currently inside a wait loop, possibly enabling a runtime optimization. (Added by JDK 9.)</td>
</tr>
<tr>
<td>void run()</td>
<td>Begins execution of a thread.</td>
</tr>
<tr>
<td>void setContextClassLoader(ClassLoader cl)</td>
<td>Sets the context class loader that will be used by the invoking thread to cl.</td>
</tr>
</tbody>
</table>
ThreadGroup
ThreadGroup creates a group of threads. It defines these two constructors:

ThreadGroup(String groupName)
ThreadGroup(ThreadGroup parentOb, String groupName)

For both forms, groupName specifies the name of the thread group. The first version creates a new group that has the current thread as its parent. In the second form, the parent is specified by parentOb. The non-deprecated methods defined by ThreadGroup are shown in Table 18-19.

Thread groups offer a convenient way to manage groups of threads as a unit. This is particularly valuable in situations in which you want to suspend and resume a number of related threads. For example, imagine a program in which one set of threads is used for printing a document, another set is used to display the document
on the screen, and another set saves the document to a disk file. If printing is aborted, you will want an easy way to stop all threads related to printing. Thread groups offer this convenience. The following program, which creates two thread groups of two threads each, illustrates this usage:
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>int activeCount()</td>
<td>Returns the approximate number of active threads in the invoking group (including those in subgroups).</td>
</tr>
<tr>
<td>int activeGroupCount()</td>
<td>Returns the approximate number of active groups (including subgroups) for which the invoking thread is a parent.</td>
</tr>
<tr>
<td>final void checkAccess()</td>
<td>Causes the security manager to verify that the invoking thread may access and/or change the group on which checkAccess() is called.</td>
</tr>
<tr>
<td>final void destroy()</td>
<td>Destroys the thread group (and any child groups) on which it is called.</td>
</tr>
<tr>
<td>int enumerate(Thread group[])</td>
<td>Puts the active threads that comprise the invoking thread group (including those in subgroups) into the <em>group</em> array.</td>
</tr>
<tr>
<td>int enumerate(Thread group[], boolean all)</td>
<td>Puts the active threads that comprise the invoking thread group into the <em>group</em> array. If <em>all</em> is true, then threads in all subgroups of the thread are also put into <em>group</em>.</td>
</tr>
<tr>
<td>int enumerate(ThreadGroup group[])</td>
<td>Puts the active subgroups (including subgroups of subgroups and so on) of the invoking thread group into the <em>group</em> array.</td>
</tr>
<tr>
<td>int enumerate(ThreadGroup group[], boolean all)</td>
<td>Puts the active subgroups of the invoking thread group into the <em>group</em> array. If <em>all</em> is true, then all active subgroups of the subgroups (and so on) are also put into <em>group</em>.</td>
</tr>
<tr>
<td>final int getMaxPriority()</td>
<td>Returns the maximum priority setting for the group.</td>
</tr>
<tr>
<td>final String getName()</td>
<td>Returns the name of the group.</td>
</tr>
<tr>
<td>final ThreadGroup getParent()</td>
<td>Returns null if the invoking ThreadGroup object has no parent. Otherwise, it returns the parent of the invoking object.</td>
</tr>
<tr>
<td>final void interrupt()</td>
<td>Invokes the interrupt() method of all threads in the group and any subgroups.</td>
</tr>
<tr>
<td>final boolean isDaemon()</td>
<td>Returns true if the group is a daemon group. Otherwise, it returns false.</td>
</tr>
<tr>
<td>boolean isDestroyed()</td>
<td>Returns true if the group has been destroyed. Otherwise, it returns false.</td>
</tr>
<tr>
<td>void list()</td>
<td>Displays information about the group.</td>
</tr>
<tr>
<td>final boolean parentOf(ThreadGroup group)</td>
<td>Returns true if the invoking thread is the parent of <em>group</em> (or <em>group</em>, itself). Otherwise, it returns false.</td>
</tr>
<tr>
<td>final void setDaemon(boolean isDaemon)</td>
<td>If isDaemon is true, then the invoking group is flagged as a daemon group.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>final void setMaxPriority(int <em>priority</em>)</td>
<td>Sets the maximum priority of the invoking group to <em>priority</em>.</td>
</tr>
<tr>
<td>String toString( )</td>
<td>Returns the string equivalent of the group.</td>
</tr>
<tr>
<td>void uncaughtException(Thread <em>thread</em>,</td>
<td>This method is called when an exception goes uncaught.</td>
</tr>
<tr>
<td>Throwable <em>e</em>)</td>
<td></td>
</tr>
</tbody>
</table>

**Table 18-19** The Methods Defined by **ThreadGroup**
// Demonstrate thread groups.

class NewThread extends Thread {
  boolean suspendFlag;

  NewThread(String threadname, ThreadGroup tgOb) {
    super(tgOb, threadname);
    System.out.println("New thread: " + this);
    suspendFlag = false;
  }

  // This is the entry point for thread.
  public void run() {
    try {
      for(int i = 5; i > 0; i--) {
        System.out.println(getName() + ": " + i);
        Thread.sleep(1000);
        synchronized(this) {
          while(suspendFlag) {
            wait();
          }
        }
      }
    } catch (Exception e) {
      System.out.println("Exception in " + getName());
    }
    System.out.println(getName() + " exiting.");
  }

  synchronized void mysuspend() {
    suspendFlag = true;
  }

  synchronized void myresume() {
    suspendFlag = false;
    notify();
  }
}
class ThreadGroupDemo {
    public static void main(String args[]) {
        ThreadGroup groupA = new ThreadGroup("Group A");
        ThreadGroup groupB = new ThreadGroup("Group B");

        NewThread ob1 = new NewThread("One", groupA);
        NewThread ob2 = new NewThread("Two", groupA);
        NewThread ob3 = new NewThread("Three", groupB);
        NewThread ob4 = new NewThread("Four", groupB);

        ob1.start();
        ob2.start();
        ob3.start();
        ob4.start();

        System.out.println("\nHere is output from list():");
        groupA.list();
        groupB.list();
        System.out.println();

        System.out.println("Suspending Group A");
        Thread tga[] = new Thread[groupA.activeCount()];
        groupA.enumerate(tga); // get threads in group
        for(int i = 0; i < tga.length; i++) {
            ((NewThread)tga[i]).mysuspend(); // suspend each thread
        }

        try {
            Thread.sleep(4000);
        } catch (InterruptedException e) {
            System.out.println("Main thread interrupted.");
        }

        System.out.println("Resuming Group A");
        for(int i = 0; i < tga.length; i++) {
            ((NewThread)tga[i]).myresume(); // resume threads in group
        }
    }
}
Sample output from this program is shown here (the precise output you see may differ):
Inside the program, notice that thread group A is suspended for four seconds. As the output confirms, this causes threads One and Two to pause, but threads Three and Four continue running. After the four seconds, threads One and Two are resumed. Notice how thread group A is suspended and resumed. First, the threads in
group A are obtained by calling `enumerate()` on group A. Then, each thread is suspended by iterating through the resulting array. To resume the threads in A, the list is again traversed and each thread is resumed.

**ThreadLocal and InheritableThreadLocal**

Java defines two additional thread-related classes in `java.lang`:

- **ThreadLocal** Used to create thread local variables. Each thread will have its own copy of a thread local variable.
- **InheritableThreadLocal** Creates thread local variables that may be inherited.

**Package**

`Package` encapsulates information about a package. The methods defined by `Package` are shown in Table 18-20. The following program demonstrates `Package`, displaying the packages about which the program currently is aware:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>&lt;A extends Annotation&gt; A getAnnotation(Class&lt;A&gt; annoType)</code></td>
<td>Returns an <code>Annotation</code> object that contains the annotation associated with <code>annoType</code> for the invoking object.</td>
</tr>
<tr>
<td><code>Annotation[] getAnnotations()</code></td>
<td>Returns all annotations associated with the invoking object in an array of <code>Annotation</code> objects. Returns a reference to this array.</td>
</tr>
<tr>
<td><code>&lt;A extends Annotation&gt; A[] getAnnotationsByType(Class&lt;A&gt; annoType)</code></td>
<td>Returns an array of the annotations (including repeated annotations) of <code>annoType</code> associated with the invoking object.</td>
</tr>
<tr>
<td><code>&lt;A extends Annotation&gt; A getDeclaredAnnotation(Class&lt;A&gt; annoType)</code></td>
<td>Returns an <code>Annotation</code> object that contains the non-inherited annotation associated with <code>annoType</code>.</td>
</tr>
<tr>
<td><code>Annotation[] getDeclaredAnnotations()</code></td>
<td>Returns an <code>Annotation</code> object for all the annotations that are declared by the invoking object. (Inherited annotations are ignored.)</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| `<A extends Annotation> A[]
getDeclaredAnnotationsByType(Class<A> annoType)`            | Returns an array of the non-inherited annotations (including repeated annotations) of `annoType` associated with the invoking object. |
| String getImplementationTitle()                                       | Returns the title of the invoking package.                                  |
| String getImplementationVendor()                                      | Returns the name of the implementor of the invoking package.                 |
| String getImplementationVersion()                                     | Returns the version number of the invoking package.                         |
| String getName()                                                       | Returns the name of the invoking package.                                   |
| static Package[] getPackages()                                        | Returns all packages about which the invoking program is currently aware.   |
| String getSpecificationTitle()                                        | Returns the title of the invoking package's specification.                   |
| String getSpecificationVendor()                                       | Returns the name of the owner of the specification for the invoking package.|
| String getSpecificationVersion()                                       | Returns the invoking package's specification version number.                 |
| int hashCode()                                                        | Returns the hash code for the invoking package.                             |
| boolean isAnnotationPresent(Class<?> extends Annotation> anno)        | Returns `true` if the annotation described by `anno` is associated with the invoking object. Returns `false` otherwise. |
| boolean isCompatibleWith(String verNum) throws NumberFormatException  | Returns `true` if `verNum` is less than or equal to the invoking package's version number. |
| boolean isSealed()                                                     | Returns `true` if the invoking package is sealed. Returns `false` otherwise. |
| boolean isSealed(URL url)                                             | Returns `true` if the invoking package is sealed relative to `url`. Returns `false` otherwise. |
| String toString()                                                     | Returns the string equivalent of the invoking package.                      |

**Table 18-20** The Methods Defined by Package
Module

Added by JDK 9, the Module class encapsulates a module. Using a Module instance you can add various access rights to a module, determine access rights, or obtain information about a module. For example, to export a package to a specified module, call addExports(); to open a package to a specified module, call addOpens(); to read another module, call addReads(); and to add a service requirement, call addUses(). You can determine if a module can access another by calling canRead(). To determine if a module uses a service, call canUse(). Although these methods will be most useful in specialized situations, Module defines several others that may be of more general interest.

For example, you can obtain the name of a module by calling getName(). If called from within a named module, the name is returned. If called from the unnamed module, null is returned. You can obtain a Set of the packages in a module by calling get Packages(). A module descriptor, in the form of a ModuleDescriptor instance, is returned by getDescriptor(). (ModuleDescriptor is a class declared in java.lang.module.) You can determine if a package is exported or opened by the invoking module by calling isExported() or isOpen(). Use isNamed() to determine if a module is named or unnamed. Other methods include getAnnotation(), getDeclaredAnnotations(), getLayer(), getClassLoader(), and getResourceAsStream(). The toString() method is also overridden for Module.

Assuming the modules defined by the examples in Chapter 16, you can easily experiment with the Module class. For example, try adding the following lines to the MyModAppDemo class:

```java
// Demonstrate Package
class PkgTest {
    public static void main(String args[]) {
        Package pkgs[];

        pkgs = Package.getPackages();

        for(int i=0; i < pkgs.length; i++)
            System.out.println(
                pkgs[i].getName() + " " +
                pkgs[i].getImplementationTitle() + " " +
                pkgs[i].getImplementationVendor() + " " +
                pkgs[i].getImplementationVersion()
            );
    }
}
```
Here, the methods `getName()` and `getPackages()` are used. Notice that a `Module` instance is obtained by calling `getModule()` on the `Class` instance for `MyModAppDemo`. When run, these lines produce the following output:

```
Module is appstart
Packages: appstart.mymodappdemo
```

### ModuleLayer

The `ModuleLayer` class, added by JDK 9, encapsulates a module layer. The nested class `ModuleLayer.Controller`, also added by JDK 9, is the controller for a module layer. In general, these classes are for specialized applications.

### RuntimePermission

`RuntimePermission` relates to Java’s security mechanism.

### Throwable

The `Throwable` class supports Java’s exception-handling system and is the class from which all exception classes are derived. It is discussed in Chapter 10.

### SecurityManager

`SecurityManager` supports Java’s security system. A reference to the current security manager can be obtained by calling `getSecurityManager()` defined by the `System` class.

### StackTraceElement

The `StackTraceElement` class describes a single stack frame, which is an individual element of a stack trace when an exception occurs. Each stack frame represents an execution point, which includes such things as the name of the class, the name of the method, the name of the file, and the source-code line number. Beginning with JDK
9, module information is also included. **StackTraceElement** defines two constructors, but typically you won’t need to use them because an array of **StackTraceElements** is returned by various methods, such as the **getStackTrace()** method of the **Throwable** and **Thread** classes.

The methods supported by **StackTraceElement** are shown in Table 18-21. These methods give you programmatic access to a stack trace.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean equals(Object (ob))</td>
<td>Returns true if the invoking StackTraceElement is the same as the one passed in (ob). Otherwise, it returns false.</td>
</tr>
<tr>
<td>String getClassLoaderName()</td>
<td>Returns the name of the class loader used to load the class in which the execution point described by the invoking StackTraceElement occurred. If the object does not include class loader information, null is returned. (Added by JDK 9.)</td>
</tr>
<tr>
<td>String getName()</td>
<td>Returns the name of the class in which the execution point described by the invoking StackTraceElement occurred.</td>
</tr>
<tr>
<td>String getFileName()</td>
<td>Returns the name of the file in which the source code of the execution point described by the invoking StackTraceElement is stored.</td>
</tr>
<tr>
<td>int getLineNumber()</td>
<td>Returns the source-code line number at which the execution point described by the invoking StackTraceElement occurred. In some situations, the line number will not be available, in which case a negative value is returned.</td>
</tr>
<tr>
<td>String getMethodName()</td>
<td>Returns the name of the method in which the execution point described by the invoking StackTraceElement occurred.</td>
</tr>
<tr>
<td>String getModuleName()</td>
<td>Returns the name of the module in which the execution point described by the invoking StackTraceElement occurred. If the object does not include module information, null is returned. (Added by JDK 9.)</td>
</tr>
<tr>
<td>String getModuleVersion()</td>
<td>Returns the version of the module in which the execution point described by the invoking StackTraceElement occurred. If the object does not include module information, null is returned. (Added by JDK 9.)</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns the hash code for the invoking StackTraceElement.</td>
</tr>
<tr>
<td>boolean isNativeMethod()</td>
<td>Returns true if the execution point described by the invoking StackTraceElement occurred in a native method. Otherwise, it returns false.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Returns the String equivalent of the invoking sequence.</td>
</tr>
</tbody>
</table>

Table 18-21  The Methods Defined by StackTraceElement

StackWalker and StackWalker.StackFrame
Added by JDK 9, the StackWalker class and the StackWalker.StackFrame
interface support stack walking operations. A StackWalker instance is obtained by use of the static getInstance() method defined by StackWalker. Stack walking is initiated by calling the walk() method of StackWalker. Each stack frame is encapsulated as a StackWalker.StackFrame object.

Enum

As described in Chapter 12, an enumeration is a list of named constants. (Recall that an enumeration is created by using the keyword enum.) All enumerations automatically inherit Enum. Enum is a generic class that is declared as shown here:

```java
class Enum<E extends Enum<E>>
```

Here, E stands for the enumeration type. Enum has no public constructors.

Enum defines several methods that are available for use by all enumerations, which are shown in Table 18-22.
Table 18-22  The Methods Defined by Enum

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>protected final Object clone()</td>
<td>Invoking this method causes a CloneNotSupportedException to be thrown. This prevents enumerations from being cloned.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>final int compareTo(E e)</td>
<td>Compares the ordinal value of two constants of the same enumeration. Returns a negative value if the invoking constant has an ordinal value less than e's, zero if the two ordinal values are the same, and a positive value if the invoking constant has an ordinal value greater than e's.</td>
</tr>
<tr>
<td>final boolean equals(Object obj)</td>
<td>Returns true if obj and the invoking object refer to the same constant.</td>
</tr>
<tr>
<td>final Class&lt;E&gt; getDeclaringClass()</td>
<td>Returns the type of enumeration of which the invoking constant is a member.</td>
</tr>
<tr>
<td>final int hashCode()</td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td>final String name()</td>
<td>Returns the unaltered name of the invoking constant.</td>
</tr>
<tr>
<td>final int ordinal()</td>
<td>Returns a value that indicates an enumeration constant's position in the list of constants.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Returns the name of the invoking constant. This name may differ from the one used in the enumeration's declaration.</td>
</tr>
<tr>
<td>static &lt;T extends Enum&lt;T&gt;&gt; T</td>
<td>Returns the constant associated with name in the enumeration type specified by e-type.</td>
</tr>
</tbody>
</table>

ClassValue

ClassValue can be used to associate a value with a type. It is a generic type defined like this:

Class ClassValue<T>

It is designed for highly specialized uses, not for normal programming.

The CharSequence Interface

The CharSequence interface defines methods that grant read-only access to a
sequence of characters. These methods are shown in Table 18-23. This interface is implemented by String, StringBuffer, and StringBuilder, among others.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>char charAt(int idx)</td>
<td>Returns the character at the index specified by idx.</td>
</tr>
<tr>
<td>default IntStream chars()</td>
<td>Returns a stream (in the form of an IntStream) to the characters in the invoking object.</td>
</tr>
<tr>
<td>default IntStream codePoints()</td>
<td>Returns a stream (in the form of an IntStream) to the code points in the invoking object.</td>
</tr>
<tr>
<td>int length()</td>
<td>Returns the number of characters in the invoking sequence.</td>
</tr>
<tr>
<td>CharSequence.subSequence(int startIdx, int stopIdx)</td>
<td>Returns a subset of the invoking sequence beginning at startIdx and ending at stopIdx-1.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Returns the String equivalent of the invoking sequence.</td>
</tr>
</tbody>
</table>

Table 18-23 The Methods Defined by CharSequence

The Comparable Interface

Objects of classes that implement Comparable can be ordered. In other words, classes that implement Comparable contain objects that can be compared in some meaningful manner. Comparable is generic and is declared like this:

```
interface Comparable<T>
```

Here, T represents the type of objects being compared.

The Comparable interface declares one method that is used to determine what Java calls the natural ordering of instances of a class. The signature of the method is shown here:

```
int compareTo(T obj)
```

This method compares the invoking object with obj. It returns 0 if the values are equal. A negative value is returned if the invoking object has a lower value. Otherwise, a positive value is returned.

This interface is implemented by several of the classes already reviewed in this book. Specifically, the Byte, Character, Double, Float, Long, Short, String, and Integer classes define a compareTo() method. So does Enum.

The Appendable Interface
An object of a class that implements Appendable can have a character or character sequences appended to it. Appendable defines these three methods:

Appendable append(char ch) throws IOException
Appendable append(CharSequence chars) throws IOException
Appendable append(CharSequence chars, int begin, int end) throws IOException

In the first form, the character ch is appended to the invoking object. In the second form, the character sequence chars is appended to the invoking object. The third form allows you to indicate a portion (the characters running from begin through end–1) of the sequence specified by chars. In all cases, a reference to the invoking object is returned.

The Iterable Interface

Iterable must be implemented by any class whose objects will be used by the for-each version of the for loop. In other words, in order for an object to be used within a for-each style for loop, its class must implement Iterable. Iterable is a generic interface that has this declaration:

```java
interface Iterable<T>
```

Here, T is the type of the object being iterated. It defines one abstract method, iterator(), which is shown here:

```java
Iterator<T> iterator()
```

It returns an iterator to the elements contained in the invoking object.

Beginning with JDK 8, Iterable also defines two default methods. The first is called forEach():

```java
default void forEach(Consumer<? super T> action)
```

For each element being iterated, forEach() executes the code specified by action. (Consumer is a functional interface added by JDK 8 and defined in java.util.function. See Chapter 20.)

The second default method is spliterator(), shown next:

```java
default Spliterator<T> spliterator()
```

It returns a Spliterator to the sequence being iterated. (See Chapters 19 and 29 for details on spliterators.)

NOTE Iterators are described in detail in Chapter 19.

The Readable Interface
The Readable interface indicates that an object can be used as a source for characters. It defines one method called read(), which is shown here:

```java
int read(CharBuffer buf) throws IOException
```

This method reads characters into `buf`. It returns the number of characters read, or –1 if an EOF is encountered.

### The AutoCloseable Interface

AutoCloseable provides support for the `try`-with-resources statement, which implements what is sometimes referred to as *automatic resource management* (ARM). The `try`-with-resources statement automates the process of releasing a resource (such as a stream) when it is no longer needed. (See Chapter 13 for details.) Only objects of classes that implement AutoCloseable can be used with `try`-with-resources. The AutoCloseable interface defines only the close() method, which is shown here:

```java
void close() throws Exception
```

This method closes the invoking object, releasing any resources that it may hold. It is automatically called at the end of a `try`-with-resources statement, thus eliminating the need to explicitly invoke close(). AutoCloseable is implemented by several classes, including all of the I/O classes that open a stream that can be closed.

### The Thread.UncaughtExceptionHandler Interface

The static Thread.UncaughtExceptionHandler interface is implemented by classes that want to handle uncaught exceptions. It is implemented by ThreadGroup. It declares only one method, which is shown here:

```java
void uncaughtException(Thread thrd, Throwable exc)
```

Here, `thrd` is a reference to the thread that generated the exception and `exc` is a reference to the exception.

### The java.lang Subpackages

Java defines several subpackages of java.lang. Except as otherwise noted, these packages are in the java.base module.

- java.lang.annotation
- java.lang.instrument
Each is briefly described here.

**java.lang.annotation**
Java’s annotation facility is supported by `java.lang.annotation`. It defines the `Annotation` interface, the `ElementType` and `RetentionPolicy` enumerations, and several predefined annotations. Annotations are described in Chapter 12.

**java.lang.instrument**
`java.lang.instrument` defines features that can be used to add instrumentation to various aspects of program execution. It defines the `Instrumentation` and `ClassFileTransformer` interfaces, and the `ClassDefinition` class. Beginning with JDK 9, this package is in the `java.instrument` module.

**java.lang.invoke**
`java.lang.invoke` supports dynamic language features. It includes classes such as `CallSite`, `MethodHandle`, and `MethodType`.

**java.lang.module**
Added by JDK 9, `java.lang.module` package supports the new modules feature. It includes classes such as `ModuleDescriptor` and `ModuleReference`, and the interfaces `ModuleFinder` and `ModuleReader`.

**java.lang.management**
The `java.lang.management` package provides management support for the JVM and the execution environment. Using the features in `java.lang.management`, you can observe and manage various aspects of program execution. Beginning with JDK 9, this package is in the `java.management` module.

**java.lang.ref**
You learned earlier that the garbage collection facilities in Java automatically determine when no references exist to an object. The object is then assumed to be no longer needed and its memory is reclaimed. The classes in the `java.lang.ref` package provide more flexible control over the garbage collection process.

**java.lang.reflect**

*Reflection* is the ability of a program to analyze code at run time. The `java.lang.reflect` package provides the ability to obtain information about the fields, constructors, methods, and modifiers of a class. Among other reasons, you need this information to build software tools that enable you to work with Java Beans components. The tools use reflection to determine dynamically the characteristics of a component. Reflection was introduced in Chapter 12 and is also examined in Chapter 30.

`java.lang.reflect` defines several classes, including `Method`, `Field`, and `Constructor`. It also defines several interfaces, including `AnnotatedElement`, `Member`, and `Type`. In addition, the `java.lang.reflect` package includes the `Array` class that enables you to create and access arrays dynamically.
This chapter begins our examination of \texttt{java.util}. This important package contains a large assortment of classes and interfaces that support a broad range of functionality. For example, \texttt{java.util} has classes that generate pseudorandom numbers, manage date and time, observe events, manipulate sets of bits, tokenize strings, and handle formatted data. The \texttt{java.util} package also contains one of Java’s most powerful subsystems: the \textit{Collections Framework}. The Collections Framework is a sophisticated hierarchy of interfaces and classes that provide state-of-the-art technology for managing groups of objects. It merits close attention by all programmers. Beginning with JDK 9, \texttt{java.util} is part of the \texttt{java.base} module.

Because \texttt{java.util} contains a wide array of functionality, it is quite large. Here is a list of its top-level classes:

<table>
<thead>
<tr>
<th>AbstractCollection</th>
<th>FormattableFlags</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>AbstractList</td>
<td>Formatter</td>
<td>PropertyPermission</td>
</tr>
<tr>
<td>AbstractMap</td>
<td>GregorianCalendar</td>
<td>PropertyResourceBundle</td>
</tr>
<tr>
<td>AbstractQueue</td>
<td>HashMap</td>
<td>Random</td>
</tr>
<tr>
<td>AbstractSequentialList</td>
<td>HashSet</td>
<td>ResourceBundle</td>
</tr>
<tr>
<td>AbstractSet</td>
<td>Hashtable</td>
<td>Scanner</td>
</tr>
<tr>
<td>ArrayDeque</td>
<td>IdentityHashMap</td>
<td>ServiceLoader</td>
</tr>
<tr>
<td>ArrayList</td>
<td>IntSummaryStatistics</td>
<td>SimpleTimeZone</td>
</tr>
<tr>
<td>Arrays</td>
<td>LinkedHashMap</td>
<td>Spliterators</td>
</tr>
<tr>
<td>Base64</td>
<td>LinkedHashSet</td>
<td>SplitableRandom</td>
</tr>
<tr>
<td>BitSet</td>
<td>LinkedList</td>
<td>Stack</td>
</tr>
</tbody>
</table>
The interfaces defined by `java.util` are shown next:

<table>
<thead>
<tr>
<th>Class</th>
<th>Class</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calendar</td>
<td>ListResourceBundle</td>
<td>StringJoiner</td>
</tr>
<tr>
<td>Collections</td>
<td>Locale</td>
<td>StringTokenizer</td>
</tr>
<tr>
<td>Currency</td>
<td>LongSummaryStatistics</td>
<td>Timer</td>
</tr>
<tr>
<td>Date</td>
<td>Objects</td>
<td>TimerTask</td>
</tr>
<tr>
<td>Dictionary</td>
<td>Observable (Deprecated by JDK 9.)</td>
<td>TimeZone</td>
</tr>
<tr>
<td>DoubleSummaryStatistics</td>
<td>Optional</td>
<td>TreeMap</td>
</tr>
<tr>
<td>EnumMap</td>
<td>OptionalDouble</td>
<td>TreeSet</td>
</tr>
<tr>
<td>EnumSet</td>
<td>OptionalInt</td>
<td>UUID</td>
</tr>
<tr>
<td>EventListenerProxy</td>
<td>OptionalLong</td>
<td>Vector</td>
</tr>
<tr>
<td>EventObject</td>
<td>PriorityQueue</td>
<td>WeakHashMap</td>
</tr>
</tbody>
</table>

Because of its size, the description of `java.util` is broken into two chapters. This chapter examines those members of `java.util` that are part of the Collections Framework. Chapter 20 discusses its other classes and interfaces.

**Collections Overview**
The Java Collections Framework standardizes the way in which groups of objects are handled by your programs. Collections were not part of the original Java release, but were added by J2SE 1.2. Prior to the Collections Framework, Java provided ad hoc classes such as Dictionary, Vector, Stack, and Properties to store and manipulate groups of objects. Although these classes were quite useful, they lacked a central, unifying theme. The way that you used Vector was different from the way that you used Properties, for example. Also, this early, ad hoc approach was not designed to be easily extended or adapted. Collections were an answer to these (and other) problems.

The Collections Framework was designed to meet several goals. First, the framework had to be high-performance. The implementations for the fundamental collections (dynamic arrays, linked lists, trees, and hash tables) are highly efficient. You seldom, if ever, need to code one of these “data engines” manually. Second, the framework had to allow different types of collections to work in a similar manner and with a high degree of interoperability. Third, extending and/or adapting a collection had to be easy. Toward this end, the entire Collections Framework is built upon a set of standard interfaces. Several standard implementations (such as LinkedList, HashSet, and TreeSet) of these interfaces are provided that you may use as-is. You may also implement your own collection, if you choose. Various special-purpose implementations are created for your convenience, and some partial implementations are provided that make creating your own collection class easier. Finally, mechanisms were added that allow the integration of standard arrays into the Collections Framework.

Algorithms are another important part of the collection mechanism. Algorithms operate on collections and are defined as static methods within the Collections class. Thus, they are available for all collections. Each collection class need not implement its own versions. The algorithms provide a standard means of manipulating collections.

Another item closely associated with the Collections Framework is the Iterator interface. An iterator offers a general-purpose, standardized way of accessing the elements within a collection, one at a time. Thus, an iterator provides a means of enumerating the contents of a collection. Because each collection provides an iterator, the elements of any collection class can be accessed through the methods defined by Iterator. Thus, with only small changes, the code that cycles through a set can also be used to cycle through a list, for example.

JDK 8 added another type of iterator called a spliterator. In brief, splitters are iterators that provide support for parallel iteration. The interfaces that support splitters are Spliterator and several nested interfaces that support primitive types. JDK 8 also added iterator interfaces designed for use with primitive types, such as
**PrimitiveIterator** and **PrimitiveIterator.OfDouble**.

In addition to collections, the framework defines several map interfaces and classes. *Maps* store key/value pairs. Although maps are part of the Collections Framework, they are not “collections” in the strict use of the term. You can, however, obtain a *collection-view* of a map. Such a view contains the elements from the map stored in a collection. Thus, you can process the contents of a map as a collection, if you choose.

The collection mechanism was retrofitted to some of the original classes defined by *java.util* so that they too could be integrated into the new system. It is important to understand that although the addition of collections altered the architecture of many of the original utility classes, it did not cause the deprecation of any. Collections simply provide a better way of doing several things.

**NOTE** If you are familiar with C++, then you will find it helpful to know that the Java collections technology is similar in spirit to the Standard Template Library (STL) defined by C++. What C++ calls a container, Java calls a collection. However, there are significant differences between the Collections Framework and the STL. It is important to not jump to conclusions.

**The Collection Interfaces**

The Collections Framework defines several core interfaces. This section provides an overview of each interface. Beginning with the collection interfaces is necessary because they determine the fundamental nature of the collection classes. Put differently, the concrete classes simply provide different implementations of the standard interfaces. The interfaces that underpin collections are summarized in the following table:
In addition to the collection interfaces, collections also use the **Comparator**, **RandomAccess**, **Iterator**, **ListIterator**, and **Spliterator** interfaces, which are described in depth later in this chapter. Briefly, **Comparator** defines how two objects are compared; **Iterator**, **ListIterator**, and **Spliterator** enumerate the objects within a collection. By implementing **RandomAccess**, a list indicates that it supports efficient, random access to its elements.

To provide the greatest flexibility in their use, the collection interfaces allow some methods to be optional. The optional methods enable you to modify the contents of a collection. Collections that support these methods are called **modifiable**. Collections that do not allow their contents to be changed are called **unmodifiable**. If an attempt is made to use one of these methods on an unmodifiable collection, an **UnsupportedOperationException** is thrown. All the built-in collections are modifiable.

The following sections examine the collection interfaces.

### The Collection Interface

The **Collection** interface is the foundation upon which the Collections Framework is built because it must be implemented by any class that defines a collection. **Collection** is a generic interface that has this declaration:

```java
interface Collection<E>
```

Here, **E** specifies the type of objects that the collection will hold. **Collection** extends the **Iterable** interface. This means that all collections can be cycled through by use of the for-each style **for** loop. (Recall that only classes that implement **Iterable** can be cycled through by the **for**.)

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collection</td>
<td>Enables you to work with groups of objects; it is at the top of the collections hierarchy.</td>
</tr>
<tr>
<td>Deque</td>
<td>Extends <strong>Queue</strong> to handle a double-ended queue.</td>
</tr>
<tr>
<td>List</td>
<td>Extends <strong>Collection</strong> to handle sequences (lists of objects).</td>
</tr>
<tr>
<td>NavigableSet</td>
<td>Extends <strong>SortedSet</strong> to handle retrieval of elements based on closest-match searches.</td>
</tr>
<tr>
<td>Queue</td>
<td>Extends <strong>Collection</strong> to handle special types of lists in which elements are removed only from the head.</td>
</tr>
<tr>
<td>Set</td>
<td>Extends <strong>Collection</strong> to handle sets, which must contain unique elements.</td>
</tr>
<tr>
<td>SortedSet</td>
<td>Extends <strong>Set</strong> to handle sorted sets.</td>
</tr>
</tbody>
</table>
**Collection** declares the core methods that all collections will have. These methods are summarized in Table 19-1. Because all collections implement **Collection**, familiarity with its methods is necessary for a clear understanding of the framework. Several of these methods can throw an **UnsupportedOperationException**. As explained, this occurs if a collection cannot be modified. A **ClassCastException** is generated when one object is incompatible with another, such as when an attempt is made to add an incompatible object to a collection. A **NullPointerException** is thrown if an attempt is made to store a null object and null elements are not allowed in the collection. An **IllegalArgumentException** is thrown if an invalid argument is used. An **IllegalStateException** is thrown if an attempt is made to add an element to a fixed-length collection that is full.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean add(E obj)</td>
<td>Adds obj to the invoking collection. Returns <strong>true</strong> if obj was added to the collection. Returns <strong>false</strong> if obj is already a member of the collection and the collection does not allow duplicates.</td>
</tr>
<tr>
<td>boolean addAll(Collection&lt;? extends E&gt; c)</td>
<td>Adds all the elements of c to the invoking collection. Returns <strong>true</strong> if the collection changed (i.e., the elements were added). Otherwise, returns <strong>false</strong>.</td>
</tr>
<tr>
<td>void clear()</td>
<td>Removes all elements from the invoking collection.</td>
</tr>
<tr>
<td>boolean contains(Object obj)</td>
<td>Returns <strong>true</strong> if obj is an element of the invoking collection. Otherwise, returns <strong>false</strong>.</td>
</tr>
<tr>
<td>boolean containsAll(Collection&lt;?&gt; c)</td>
<td>Returns <strong>true</strong> if the invoking collection contains all elements of c. Otherwise, returns <strong>false</strong>.</td>
</tr>
<tr>
<td>boolean equals(Object obj)</td>
<td>Returns <strong>true</strong> if the invoking collection and obj are equal. Otherwise, returns <strong>false</strong>.</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns the hash code for the invoking collection.</td>
</tr>
<tr>
<td>boolean isEmpty()</td>
<td>Returns <strong>true</strong> if the invoking collection is empty. Otherwise, returns <strong>false</strong>.</td>
</tr>
<tr>
<td>Iterator&lt;E&gt; iterator()</td>
<td>Returns an iterator for the invoking collection.</td>
</tr>
<tr>
<td>default Stream&lt;E&gt; parallelStream()</td>
<td>Returns a stream that uses the invoking collection as its source for elements. If possible, the stream supports parallel operations.</td>
</tr>
<tr>
<td>Method (Type)</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td><code>boolean remove(Object obj)</code></td>
<td>Removes one instance of <code>obj</code> from the invoking collection. Returns <code>true</code> if the element was removed. Otherwise, returns <code>false</code>.</td>
</tr>
<tr>
<td><code>boolean removeAll(Collection&lt;? super E&gt; c)</code></td>
<td>Removes all elements of <code>c</code> from the invoking collection. Returns <code>true</code> if the collection changed (i.e., elements were removed). Otherwise, returns <code>false</code>.</td>
</tr>
<tr>
<td><code>default boolean removeIf(Predicate&lt;? super E&gt; predicate)</code></td>
<td>Removes from the invoking collection those elements that satisfy the condition specified by <code>predicate</code>.</td>
</tr>
<tr>
<td><code>boolean retainAll(Collection&lt;? super E&gt; c)</code></td>
<td>Removes all elements from the invoking collection except those in <code>c</code>. Returns <code>true</code> if the collection changed (i.e., elements were removed). Otherwise, returns <code>false</code>.</td>
</tr>
<tr>
<td><code>int size()</code></td>
<td>Returns the number of elements held in the invoking collection.</td>
</tr>
<tr>
<td><code>default Spliterator&lt;E&gt; spliterator()</code></td>
<td>Returns a spliterator to the invoking collections.</td>
</tr>
<tr>
<td><code>default Stream&lt;E&gt; stream()</code></td>
<td>Returns a stream that uses the invoking collection as its source for elements. The stream is sequential.</td>
</tr>
<tr>
<td><code>Object[] toArray()</code></td>
<td>Returns an array that contains all the elements stored in the invoking collection. The array elements are copies of the collection elements.</td>
</tr>
<tr>
<td><code>&lt;T&gt; T[] toArray(T array[])</code></td>
<td>Returns an array that contains the elements of the invoking collection. The array elements are copies of the collection elements. If the size of <code>array</code> equals the number of elements, these are returned in <code>array</code>. If the size of <code>array</code> is less than the number of elements, a new array of the necessary size is allocated and returned. If the size of <code>array</code> is greater than the number of elements, the array element following the last collection element is set to <code>null</code>. An <code>ArrayStoreException</code> is thrown if any collection element has a type that is not a subtype of <code>array</code>.</td>
</tr>
</tbody>
</table>

Table 19-1  The Methods Declared by `Collection`

Objects are added to a collection by calling `add()`. Notice that `add()` takes an argument of type `E`, which means that objects added to a collection must be compatible with the type of data expected by the collection. You can add the entire contents of one collection to another by calling `addAll()`. You can remove an object by using `remove()`. To remove a group of objects, call
removeAll( ). You can remove all elements except those of a specified group by calling retainAll( ). To remove an element only if it satisfies some condition, you can use removeIf( ). To empty a collection, call clear( ).

You can determine whether a collection contains a specific object by calling contains( ). To determine whether one collection contains all the members of another, call containsAll( ). You can determine when a collection is empty by calling isEmpty( ). The number of elements currently held in a collection can be determined by calling size( ).

The toArray( ) methods return an array that contains the elements stored in the collection. The first returns an array of Object. The second returns an array of elements that have the same type as the array specified as a parameter. Normally, the second form is more convenient because it returns the desired array type. These methods are more important than it might at first seem. Often, processing the contents of a collection by using array-like syntax is advantageous. By providing a pathway between collections and arrays, you can have the best of both worlds.

Two collections can be compared for equality by calling equals( ). The precise meaning of “equality” may differ from collection to collection. For example, you can implement equals( ) so that it compares the values of elements stored in the collection. Alternatively, equals( ) can compare references to those elements.

Another important method is iterator( ), which returns an iterator to a collection. The spliterator( ) method returns a spliterator to the collection. Iterators are frequently used when working with collections. Finally, the stream( ) and parallelStream( ) methods return a Stream that uses the collection as a source of elements. (See Chapter 29 for a detailed discussion of the new Stream interface.)

The List Interface

The List interface extends Collection and declares the behavior of a collection that stores a sequence of elements. Elements can be inserted or accessed by their position in the list, using a zero-based index. A list may contain duplicate elements. List is a generic interface that has this declaration:

```
interface List<E>
```

Here, E specifies the type of objects that the list will hold.

In addition to the methods defined by Collection, List defines some of its own, which are summarized in Table 19-2. Note again that several of these methods will throw an UnsupportedOperationException if the list cannot be modified, and a ClassCastException is generated when one object is incompatible with another, such as when an attempt is made to add an incompatible object to a list. Also, several methods will throw an IndexOutOfBoundsException if an invalid index is used. A
NullPointerException is thrown if an attempt is made to store a null object and null elements are not allowed in the list. An IllegalArgumentException is thrown if an invalid argument is used.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void add(int index, E obj)</code></td>
<td>Inserts <code>obj</code> into the invoking list at the index passed in <code>index</code>. Any preexisting elements at or beyond the point of insertion are shifted up. Thus, no elements are overwritten.</td>
</tr>
<tr>
<td><code>boolean addAll(int index, Collection&lt;? extends E&gt; c)</code></td>
<td>Inserts all elements of <code>c</code> into the invoking list at the index passed in <code>index</code>. Any preexisting elements at or beyond the point of insertion are shifted up. Thus, no elements are overwritten. Returns <code>true</code> if the invoking list changes and returns <code>false</code> otherwise.</td>
</tr>
<tr>
<td><code>E get(int index)</code></td>
<td>Returns the object stored at the specified index within the invoking collection.</td>
</tr>
<tr>
<td><code>int indexOf(Object obj)</code></td>
<td>Returns the index of the first instance of <code>obj</code> in the invoking list. If <code>obj</code> is not an element of the list, –1 is returned.</td>
</tr>
<tr>
<td><code>int lastIndexOf(Object obj)</code></td>
<td>Returns the index of the last instance of <code>obj</code> in the invoking list. If <code>obj</code> is not an element of the list, –1 is returned.</td>
</tr>
<tr>
<td><code>ListIterator&lt;E&gt; listIterator()</code></td>
<td>Returns an iterator to the start of the invoking list.</td>
</tr>
<tr>
<td><code>ListIterator&lt;E&gt; listIterator(int index)</code></td>
<td>Returns an iterator to the invoking list that begins at the specified <code>index</code>.</td>
</tr>
<tr>
<td><code>static &lt;E&gt; List&lt;E&gt; of( parameter-list )</code></td>
<td>Creates an unmodifiable list containing the elements specified in <code>parameter-list</code>. Null elements are not allowed. Many overloaded versions are provided. See the discussion in the text for details. (Added by JDK 9.)</td>
</tr>
<tr>
<td><code>E remove(int index)</code></td>
<td>Removes the element at position <code>index</code> from the invoking list and returns the deleted element. The resulting list is compacted. That is, the indexes of subsequent elements are decremented by one.</td>
</tr>
<tr>
<td><code>default void replaceAll(UnaryOperator&lt;E&gt; opToApply)</code></td>
<td>Updates each element in the list with the value obtained from the <code>opToApply</code> function.</td>
</tr>
<tr>
<td><code>E set(int index, E obj)</code></td>
<td>Assigns <code>obj</code> to the location specified by <code>index</code> within the invoking list. Returns the old value.</td>
</tr>
<tr>
<td><code>default void sort(Comparator&lt;? super E&gt; comp)</code></td>
<td>Sorts the list using the comparator specified by <code>comp</code>.</td>
</tr>
<tr>
<td><code>List&lt;E&gt; subList(int start, int end)</code></td>
<td>Returns a list that includes elements from <code>start</code> to <code>end−1</code> in the invoking list. Elements in the returned list are also referenced by the invoking object.</td>
</tr>
</tbody>
</table>
Table 19-2  The Methods Declared by List

To the versions of add( ) and addAll( ) defined by Collection, List adds the methods add(int, E) and addAll(int, Collection). These methods insert elements at the specified index. Also, the semantics of add(E) and addAll(Collection) defined by Collection are changed by List so that they add elements to the end of the list. You can modify each element in the collection by using replaceAll( ).

To obtain the object stored at a specific location, call get( ) with the index of the object. To assign a value to an element in the list, call set( ), specifying the index of the object to be changed. To find the index of an object, use indexOf( ) or lastIndexOf( ).

You can obtain a sublist of a list by calling subList( ), specifying the beginning and ending indexes of the sublist. As you can imagine, subList( ) makes list processing quite convenient. One way to sort a list is with the sort( ) method defined by List.

Beginning with JDK 9, List includes the of( ) factory method, which has a number of overloads. Each version returns an unmodifiable, value-based collection that is comprised of the arguments that it is passed. The primary purpose of of( ) is to provide a convenient, efficient way to create a small List collection. There are 12 overloads of of( ). One takes no arguments and creates an empty list. It is shown here:

static <E> List<E> of( )

Ten overloads take from 1 to 10 arguments and create a list that contains the specified elements. They are shown here:

static <E> List<E> of(E obj1)
static <E> List<E> of(E obj1, E obj2)
static <E> List<E> of(E obj, E obj2, E obj3)
...
static <E> List<E> of(E ob1, E obj2, E obj3, E obj4, E obj5, E obj6, E obj7, E obj8, E obj9, E obj10)

The final of( ) overload specifies a varargs parameter that takes an arbitrary number of elements or an array of elements. It is shown here:

static <E> List<E> of(E … objs)

For all versions, null elements are not allowed. In all cases, the List implementation is unspecified.
The Set Interface

The Set interface defines a set. It extends Collection and specifies the behavior of a collection that does not allow duplicate elements. Therefore, the add() method returns false if an attempt is made to add duplicate elements to a set. With one exception, it does not specify any additional methods of its own. Set is a generic interface that has this declaration:

interface Set<E>

Here, E specifies the type of objects that the set will hold.

Beginning with JDK 9, Set includes the of() factory method, which has a number of overloads. Each version returns an unmodifiable, value-based collection that is comprised of the arguments that it is passed. The primary purpose of of() is to provide a convenient, efficient way to create a small Set collection. There are 12 overloads of of(). One takes no arguments and creates an empty set. It is shown here:

static <E> Set<E> of( )

Ten overloads take from 1 to 10 arguments and create a list that contains the specified elements. They are shown here:

static <E> Set<E> of(E obj1)
static <E> Set<E> of(E obj1, E obj2)
static <E> Set<E> of(E obj, E obj2, E obj3)
...
static <E> Set<E> of(E obj1, E obj2, E obj3, E obj4, E obj5, E obj6, E obj7, E obj8, E obj9, E obj10)

The final of() overload specifies a varargs parameter that takes an arbitrary number of elements or an array of elements. It is shown here:

static <E> Set<E> of(E ... objs)

For all versions, null elements are not allowed. In all cases, the Set implementation is unspecified.

The SortedSet Interface

The SortedSet interface extends Set and declares the behavior of a set sorted in ascending order. SortedSet is a generic interface that has this declaration:

interface SortedSet<E>

Here, E specifies the type of objects that the set will hold.

In addition to those methods provided by Set, the SortedSet interface declares the
Several methods throw a `NoSuchElementException` when no items are contained in the invoking set. A `ClassCastException` is thrown when an object is incompatible with the elements in a set. A `NullPointerException` is thrown if an attempt is made to use a `null` object and `null` is not allowed in the set. An `IllegalArgumentException` is thrown if an invalid argument is used.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>Comparator&lt;? super E&gt; comparator( )</code></td>
<td>Returns the invoking sorted set’s comparator. If the natural ordering is used for this set, <code>null</code> is returned.</td>
</tr>
<tr>
<td><code>E first( )</code></td>
<td>Returns the first element in the invoking sorted set.</td>
</tr>
<tr>
<td><code>SortedSet&lt;E&gt; headSet(E end)</code></td>
<td>Returns a <code>SortedSet</code> containing those elements less than <code>end</code> that are contained in the invoking sorted set. Elements in the returned sorted set are also referenced by the invoking sorted set.</td>
</tr>
<tr>
<td><code>E last( )</code></td>
<td>Returns the last element in the invoking sorted set.</td>
</tr>
<tr>
<td><code>SortedSet&lt;E&gt; subSet(E start, E end)</code></td>
<td>Returns a <code>SortedSet</code> that includes those elements between <code>start</code> and <code>end−1</code>. Elements in the returned collection are also referenced by the invoking set.</td>
</tr>
<tr>
<td><code>SortedSet&lt;E&gt; tailSet(E start)</code></td>
<td>Returns a <code>SortedSet</code> that contains those elements greater than or equal to <code>start</code> that are contained in the sorted set. Elements in the returned set are also referenced by the invoking object.</td>
</tr>
</tbody>
</table>

**Table 19-3** The Methods Declared by `SortedSet`

`SortedSet` defines several methods that make set processing more convenient. To obtain the first object in the set, call `first( )`. To get the last element, use `last( )`. You can obtain a subset of a sorted set by calling `subSet( )`, specifying the first and last object in the set. If you need the subset that starts with the first element in the set, use `headSet( )`. If you want the subset that ends the set, use `tailSet( )`.

**The NavigableSet Interface**

The `NavigableSet` interface extends `SortedSet` and declares the behavior of a collection that supports the retrieval of elements based on the closest match to a given value or values. `NavigableSet` is a generic interface that has this declaration:

```java
interface NavigableSet<E>
```
Here, `E` specifies the type of objects that the set will hold. In addition to the methods that it inherits from `SortedSet, NavigableSet` adds those summarized in Table 19-4. A `ClassCastException` is thrown when an object is incompatible with the elements in the set. A `NullPointerException` is thrown if an attempt is made to use a `null` object and `null` is not allowed in the set. An `IllegalArgumentException` is thrown if an invalid argument is used.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>E ceiling(E obj)</td>
<td>Searches the set for the smallest element e such that e &gt;= obj. If such an element is found, it is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td>Iterator&lt;E&gt; descendingIterator()</td>
<td>Returns an iterator that moves from the greatest to least. In other words, it returns a reverse iterator.</td>
</tr>
<tr>
<td>NavigableSet&lt;E&gt; descendingSet()</td>
<td>Returns a NavigableSet that is the reverse of the invoking set. The resulting set is backed by the invoking set.</td>
</tr>
<tr>
<td>E floor(E obj)</td>
<td>Searches the set for the largest element e such that e &lt;= obj. If such an element is found, it is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td>NavigableSet&lt;E&gt;</td>
<td>headSet(E upperBound, boolean incl) Returns a NavigableSet that includes all elements from the invoking set that are less than upperBound. If incl is true, then an element equal to upperBound is included. The resulting set is backed by the invoking set.</td>
</tr>
<tr>
<td>E higher(E obj)</td>
<td>Searches the set for the smallest element e such that e &gt; obj. If such an element is found, it is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td>E lower(E obj)</td>
<td>Searches the set for the largest element e such that e &lt; obj. If such an element is found, it is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td>E pollFirst()</td>
<td>Returns the first element, removing the element in the process. Because the set is sorted, this is the element with the least value. null is returned if the set is empty.</td>
</tr>
<tr>
<td>E pollLast()</td>
<td>Returns the last element, removing the element in the process. Because the set is sorted, this is the element with the greatest value. null is returned if the set is empty.</td>
</tr>
<tr>
<td>NavigableSet&lt;E&gt;</td>
<td>subSet(E lowerBound, boolean lowIncl, E upperBound, boolean highIncl) Returns a NavigableSet that includes all elements from the invoking set that are greater than lowerBound and less than upperBound. If lowIncl is true, then an element equal to lowerBound is included. If highIncl is true, then an element equal to upperBound is included. The resulting set is backed by the invoking set.</td>
</tr>
<tr>
<td>NavigableSet&lt;E&gt;</td>
<td>tailSet(E lowerBound, boolean incl) Returns a NavigableSet that includes all elements from the invoking set that are greater than lowerBound. If incl is true, then an element equal to lowerBound is included. The resulting set is backed by the invoking set.</td>
</tr>
</tbody>
</table>

Table 19-4  The Methods Declared by NavigableSet

The Queue Interface
The **Queue** interface extends **Collection** and declares the behavior of a queue, which is often a first-in, first-out list. However, there are types of queues in which the ordering is based upon other criteria. **Queue** is a generic interface that has this declaration:

```java
interface Queue<E>
```

Here, `E` specifies the type of objects that the queue will hold. The methods declared by **Queue** are shown in **Table 19-5**.

![Table 19-5](image)

Table 19-5  The Methods Declared by **Queue**

Several methods throw a **ClassCastException** when an object is incompatible with the elements in the queue. A **NullPointerException** is thrown if an attempt is made to store a `null` object and `null` elements are not allowed in the queue. An **IllegalArgumentException** is thrown if an invalid argument is used. An **IllegalStateException** is thrown if an attempt is made to add an element to a fixed-length queue that is full. A **NoSuchElementException** is thrown if an attempt is made to remove an element from an empty queue.

Despite its simplicity, **Queue** offers several points of interest. First, elements can only be removed from the head of the queue. Second, there are two methods that obtain and remove elements: `poll()` and `remove()`. The difference between them is that `poll()` returns `null` if the queue is empty, but `remove()` throws an exception. Third, there are two methods, `element()` and `peek()`, that obtain but don’t remove the element at the head of the queue. They differ only in that `element()` throws an exception if the queue is empty, but `peek()` returns `null`. Finally, notice that `offer()` only attempts to add an element to a queue. Because some queues have a fixed length and might be full, `offer()` can fail.
The Deque Interface

The Deque interface extends Queue and declares the behavior of a double-ended queue. Double-ended queues can function as standard, first-in, first-out queues or as last-in, first-out stacks. Deque is a generic interface that has this declaration:

    interface Deque<E>

Here, E specifies the type of objects that the deque will hold. In addition to the methods that it inherits from Queue, Deque adds those methods summarized in Table 19-6. Several methods throw a ClassCastException when an object is incompatible with the elements in the deque. A NullPointerException is thrown if an attempt is made to store a null object and null elements are not allowed in the deque. An IllegalArgumentException is thrown if an invalid argument is used. An IllegalStateException is thrown if an attempt is made to add an element to a fixed-length deque that is full. A NoSuchElementException is thrown if an attempt is made to remove an element from an empty deque.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void addFirst(E obj)</code></td>
<td>Adds <code>obj</code> to the head of the deque. Throws an <code>IllegalStateException</code> if a capacity-restricted deque is out of space.</td>
</tr>
<tr>
<td><code>void addLast(E obj)</code></td>
<td>Adds <code>obj</code> to the tail of the deque. Throws an <code>IllegalStateException</code> if a capacity-restricted deque is out of space.</td>
</tr>
<tr>
<td><code>Iterator&lt;E&gt; descendingIterator()</code></td>
<td>Returns an iterator that moves from the tail to the head of the deque. In other words, it returns a reverse iterator.</td>
</tr>
<tr>
<td><code>E getFirst()</code></td>
<td>Returns the first element in the deque. The object is not removed from the deque. It throws <code>NoSuchElementException</code> if the deque is empty.</td>
</tr>
<tr>
<td><code>E getLast()</code></td>
<td>Returns the last element in the deque. The object is not removed from the deque. It throws <code>NoSuchElementException</code> if the deque is empty.</td>
</tr>
<tr>
<td><code>boolean offerFirst(E obj)</code></td>
<td>Attempts to add <code>obj</code> to the head of the deque. Returns <code>true</code> if <code>obj</code> was added and <code>false</code> otherwise. Therefore, this method returns <code>false</code> when an attempt is made to add <code>obj</code> to a full, capacity-restricted deque.</td>
</tr>
<tr>
<td><code>boolean offerLast(E obj)</code></td>
<td>Attempts to add <code>obj</code> to the tail of the deque. Returns <code>true</code> if <code>obj</code> was added and <code>false</code> otherwise.</td>
</tr>
<tr>
<td><code>E peekFirst()</code></td>
<td>Returns the element at the head of the deque. It returns <code>null</code> if the deque is empty. The object is not removed.</td>
</tr>
<tr>
<td><code>E peekLast()</code></td>
<td>Returns the element at the tail of the deque. It returns <code>null</code> if the deque is empty. The object is not removed.</td>
</tr>
<tr>
<td><code>E pollFirst()</code></td>
<td>Returns the element at the head of the deque, removing the element in the process. It returns <code>null</code> if the deque is empty.</td>
</tr>
<tr>
<td><code>E pollLast()</code></td>
<td>Returns the element at the tail of the deque, removing the element in the process. It returns <code>null</code> if the deque is empty.</td>
</tr>
<tr>
<td><code>E pop()</code></td>
<td>Returns the element at the head of the deque, removing it in the process. It throws <code>NoSuchElementException</code> if the deque is empty.</td>
</tr>
</tbody>
</table>
Notice that Deque includes the methods push( ) and pop( ). These methods enable a Deque to function as a stack. Also, notice the descendingIterator( ) method. It returns an iterator that returns elements in reverse order. In other words, it returns an iterator that moves from the end of the collection to the start. A Deque implementation can be capacity-restricted, which means that only a limited number of elements can be added to the deque. When this is the case, an attempt to add an element to the deque can fail. Deque allows you to handle such a failure in two ways. First, methods such as addFirst( ) and addLast( ) throw an IllegalStateException if a capacity-restricted deque is full. Second, methods such as offerFirst( ) and offerLast( ) return false if the element cannot be added.

The Collection Classes

Now that you are familiar with the collection interfaces, you are ready to examine the standard classes that implement them. Some of the classes provide full implementations that can be used as-is. Others are abstract, providing skeletal implementations that are used as starting points for creating concrete collections. As a general rule, the collection classes are not synchronized, but as you will see later in this chapter, it is possible to obtain synchronized versions.

The core collection classes are summarized in the following table:

<table>
<thead>
<tr>
<th>Method or Method Signature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void push(E obj)</td>
<td>Adds obj to the head of the deque. Throws an IllegalStateException if a capacity-restricted deque is out of space.</td>
</tr>
<tr>
<td>E removeFirst( )</td>
<td>Returns the element at the head of the deque, removing the element in the process. It throws NoSuchElementException if the deque is empty.</td>
</tr>
<tr>
<td>boolean removeFirstOccurrence(Object obj)</td>
<td>Removes the first occurrence of obj from the deque. Returns true if successful and false if the deque did not contain obj.</td>
</tr>
<tr>
<td>E removeLast( )</td>
<td>Returns the element at the tail of the deque, removing the element in the process. It throws NoSuchElementException if the deque is empty.</td>
</tr>
<tr>
<td>boolean removeLastOccurrence(Object obj)</td>
<td>Removes the last occurrence of obj from the deque. Returns true if successful and false if the deque did not contain obj.</td>
</tr>
</tbody>
</table>

Table 19-6 The Methods Declared by Deque
The following sections examine the concrete collection classes and illustrate their use.

**NOTE** In addition to the collection classes, several legacy classes, such as Vector, Stack, and Hashtable, have been reengineered to support collections. These are examined later in this chapter.

### The ArrayList Class

The **ArrayList** class extends **AbstractList** and implements the **List** interface. **ArrayList** is a generic class that has this declaration:

```java
class ArrayList<E>
```

Here, `E` specifies the type of objects that the list will hold.

**ArrayList** supports dynamic arrays that can grow as needed. In Java, standard arrays are of a fixed length. After arrays are created, they cannot grow or shrink, which means that you must know in advance how many elements an array will hold. But, sometimes, you may not know until run time precisely how large an array you need. To handle this situation, the Collections Framework defines **ArrayList**. In essence, an **ArrayList** is a variable-length array of object references. That is, an
**ArrayList** can dynamically increase or decrease in size. Array lists are created with an initial size. When this size is exceeded, the collection is automatically enlarged. When objects are removed, the array can be shrunk.

**NOTE** Dynamic arrays are also supported by the legacy class Vector, which is described later in this chapter.

**ArrayList** has the constructors shown here:

- ArrayList( )
- ArrayList(Collection<? extends E> c)
- ArrayList(int capacity)

The first constructor builds an empty array list. The second constructor builds an array list that is initialized with the elements of the collection c. The third constructor builds an array list that has the specified initial *capacity*. The capacity is the size of the underlying array that is used to store the elements. The capacity grows automatically as elements are added to an array list.

The following program shows a simple use of ArrayList. An array list is created for objects of type String, and then several strings are added to it. (Recall that a quoted string is translated into a String object.) The list is then displayed. Some of the elements are removed and the list is displayed again.
// Demonstrate ArrayList.
import java.util.*;

class ArrayListDemo {
    public static void main(String args[]) {
        // Create an array list.
        ArrayList<String> al = new ArrayList<String>();

        System.out.println("Initial size of al: " +
                           al.size());

        // Add elements to the array list.
        al.add("C");
        al.add("A");
        al.add("E");
        al.add("B");
        al.add("D");
        al.add("F");
        al.add(1, "A2");

        System.out.println("Size of al after additions: " +
                           al.size());

        // Display the array list.
        System.out.println("Contents of al: " + al);

        // Remove elements from the array list.
        al.remove("F");
        al.remove(2);

        System.out.println("Size of al after deletions: " +
                           al.size());

        System.out.println("Contents of al: " + al);
    }
}

The output from this program is shown here:

Initial size of al: 0
Size of al after additions: 7
Contents of al: [C, A2, A, E, B, D, F]
Size of al after deletions: 5
Contents of al: [C, A2, E, B, D]
Notice that a1 starts out empty and grows as elements are added to it. When elements are removed, its size is reduced.

In the preceding example, the contents of a collection are displayed using the default conversion provided by toString(), which was inherited from AbstractCollection. Although it is sufficient for short, sample programs, you seldom use this method to display the contents of a real-world collection. Usually, you provide your own output routines. But, for the next few examples, the default output created by toString() is sufficient.

Although the capacity of an ArrayList object increases automatically as objects are stored in it, you can increase the capacity of an ArrayList object manually by calling ensureCapacity(). You might want to do this if you know in advance that you will be storing many more items in the collection than it can currently hold. By increasing its capacity once, at the start, you can prevent several reallocations later. Because reallocations are costly in terms of time, preventing unnecessary ones improves performance. The signature for ensureCapacity() is shown here:

```java
void ensureCapacity(int cap)
```
Here, `cap` specifies the new minimum capacity of the collection.

Conversely, if you want to reduce the size of the array that underlies an ArrayList object so that it is precisely as large as the number of items that it is currently holding, call trimToSize(), shown here:

```java
void trimToSize()
```

**Obtaining an Array from an ArrayList**

When working with ArrayList, you will sometimes want to obtain an actual array that contains the contents of the list. You can do this by calling toArray(), which is defined by Collection. Several reasons exist why you might want to convert a collection into an array, such as:

- To obtain faster processing times for certain operations
- To pass an array to a method that is not overloaded to accept a collection
- To integrate collection-based code with legacy code that does not understand collections

Whatever the reason, converting an ArrayList to an array is a trivial matter.

As explained earlier, there are two versions of toArray(), which are shown again here for your convenience:

```java
object[ ] toArray()
```
The first returns an array of `Object`. The second returns an array of elements that have the same type as `T`. Normally, the second form is more convenient because it returns the proper type of array. The following program demonstrates its use:

```java
// Convert an ArrayList into an array.
import java.util.*;

class ArrayListToArray {
    public static void main(String args[]) {
        // Create an array list.
        ArrayList<Integer> al = new ArrayList<Integer>(
            new Integer[al.size()]);
        ia = al.toArray(ia);

        System.out.println("Contents of al: " + al);

        // Get the array.
        Integer ia[] = new Integer[al.size()];
        ia = al.toArray(ia);

        int sum = 0;

        // Sum the array.
        for(int i : ia) sum += i;

        System.out.println("Sum is: " + sum);
    }
}
```

The output from the program is shown here:

```
Contents of al: [1, 2, 3, 4]
Sum is: 10
```

The program begins by creating a collection of integers. Next, `toArray()` is called and it obtains an array of `Integers`. Then, the contents of that array are summed by use of a for-each style `for` loop.

There is something else of interest in this program. As you know, collections can store only references, not values of primitive types. However, autoboxing makes it...
possible to pass values of type \texttt{int} to \texttt{add()} without having to manually wrap them within an \texttt{Integer}, as the program shows. Autoboxing causes them to be automatically wrapped. In this way, autoboxing significantly improves the ease with which collections can be used to store primitive values.

**The LinkedList Class**

The \texttt{LinkedList} class extends \texttt{AbstractSequentialList} and implements the \texttt{List}, \texttt{Deque}, and \texttt{Queue} interfaces. It provides a linked-list data structure. \texttt{LinkedList} is a generic class that has this declaration:

\begin{verbatim}
    class LinkedList\langle E \rangle
\end{verbatim}

Here, \texttt{E} specifies the type of objects that the list will hold. \texttt{LinkedList} has the two constructors shown here:

\begin{verbatim}
    LinkedList( )
    LinkedList(Collection<? extends E> c)
\end{verbatim}

The first constructor builds an empty linked list. The second constructor builds a linked list that is initialized with the elements of the collection \texttt{c}.

Because \texttt{LinkedList} implements the \texttt{Deque} interface, you have access to the methods defined by \texttt{Deque}. For example, to add elements to the start of a list, you can use \texttt{addFirst()} or \texttt{offerFirst()}. To add elements to the end of the list, use \texttt{addLast()} or \texttt{offerLast()}. To obtain the first element, you can use \texttt{getFirst()} or \texttt{peekFirst()}. To obtain the last element, use \texttt{getLast()} or \texttt{peekLast()}. To remove the first element, use \texttt{removeFirst()} or \texttt{pollFirst()}. To remove the last element, use \texttt{removeLast()} or \texttt{pollLast()}.

The following program illustrates \texttt{LinkedList}:
// Demonstrate LinkedList.
import java.util.*;

class LinkedListDemo {
    public static void main(String args[]) {
        // Create a linked list.
        LinkedList<String> ll = new LinkedList<String>();

        // Add elements to the linked list.
        ll.add("F");
        ll.add("B");
        ll.add("D");
        ll.add("E");
        ll.add("C");
        ll.addLast("Z");
        ll.addFirst("A");

        ll.add(1, "A2");

        System.out.println("Original contents of ll: " + ll);

        // Remove elements from the linked list.
        ll.remove("F");
        ll.remove(2);

        System.out.println("Contents of ll after deletion: "
                         + ll);

        // Remove first and last elements.
        ll.removeFirst();
        ll.removeLast();

        System.out.println("ll after deleting first and last: "
                           + ll);

        // Get and set a value.
        String val = ll.get(2);
        ll.set(2, val + " Changed");

        System.out.println("ll after change: " + ll);
    }
}
The output from this program is shown here:

Original contents of ll: [A, A2, F, B, D, E, C, Z]
Contents of ll after deletion: [A, A2, D, E, C, Z]
ll after deleting first and last: [A2, D, E, C]
ll after change: [A2, D, E Changed, C]

Because LinkedList implements the List interface, calls to add(E) append items to the end of the list, as do calls to addLast( ). To insert items at a specific location, use the add(int, E) form of add( ), as illustrated by the call to add(1, "A2") in the example.

Notice how the third element in ll is changed by employing calls to get( ) and set( ). To obtain the current value of an element, pass get( ) the index at which the element is stored. To assign a new value to that index, pass set( ) the index and its new value.

The HashSet Class
HashSet extends AbstractSet and implements the Set interface. It creates a collection that uses a hash table for storage. HashSet is a generic class that has this declaration:

    class HashSet<E>

Here, E specifies the type of objects that the set will hold.

As most readers likely know, a hash table stores information by using a mechanism called hashing. In hashing, the informational content of a key is used to determine a unique value, called its hash code. The hash code is then used as the index at which the data associated with the key is stored. The transformation of the key into its hash code is performed automatically—you never see the hash code itself. Also, your code can’t directly index the hash table. The advantage of hashing is that it allows the execution time of add( ), contains( ), remove( ), and size( ) to remain constant even for large sets.

The following constructors are defined:

    HashSet( )
    HashSet(Collection<? extends E> c)
    HashSet(int capacity)
    HashSet(int capacity, float fillRatio)

The first form constructs a default hash set. The second form initializes the hash set by using the elements of c. The third form initializes the capacity of the hash set to
capacity. (The default capacity is 16.) The fourth form initializes both the capacity and the fill ratio (also called load factor) of the hash set from its arguments. The fill ratio must be between 0.0 and 1.0, and it determines how full the hash set can be before it is resized upward. Specifically, when the number of elements is greater than the capacity of the hash set multiplied by its fill ratio, the hash set is expanded. For constructors that do not take a fill ratio, 0.75 is used.

HashSet does not define any additional methods beyond those provided by its superclasses and interfaces.

It is important to note that HashSet does not guarantee the order of its elements, because the process of hashing doesn’t usually lend itself to the creation of sorted sets. If you need sorted storage, then another collection, such as TreeSet, is a better choice.

Here is an example that demonstrates HashSet:

```java
// Demonstrate HashSet.
import java.util.*;

class HashSetDemo {
    public static void main(String args[]) {
        // Create a hash set.
        HashSet<String> hs = new HashSet<String>();

        // Add elements to the hash set.
        hs.add("Beta");
        hs.add("Alpha");
        hs.add("Eta");
        hs.add("Gamma");
        hs.add("Epsilon");
        hs.add("Omega");

        System.out.println(hs);
    }
}
```

The following is the output from this program:

```
[Gamma, Eta, Alpha, Epsilon, Omega, Beta]
```

As explained, the elements are not stored in sorted order, and the precise output may vary.

The LinkedHashSet Class
The **LinkedHashSet** class extends **HashSet** and adds no members of its own. It is a generic class that has this declaration:

```java
class LinkedHashSet<E>
```

Here, `E` specifies the type of objects that the set will hold. Its constructors parallel those in **HashSet**.

**LinkedHashSet** maintains a linked list of the entries in the set, in the order in which they were inserted. This allows insertion-order iteration over the set. That is, when cycling through a **LinkedHashSet** using an iterator, the elements will be returned in the order in which they were inserted. This is also the order in which they are contained in the string returned by `toString()` when called on a **LinkedHashSet** object. To see the effect of **LinkedHashSet**, try substituting **LinkedHashSet** for **HashSet** in the preceding program. The output will be

```
[Beta, Alpha, Eta, Gamma, Epsilon, Omega]
```

which is the order in which the elements were inserted.

**The TreeSet Class**

**TreeSet** extends **AbstractSet** and implements the **NavigableSet** interface. It creates a collection that uses a tree for storage. Objects are stored in sorted, ascending order. Access and retrieval times are quite fast, which makes **TreeSet** an excellent choice when storing large amounts of sorted information that must be found quickly.

**TreeSet** is a generic class that has this declaration:

```java
class TreeSet<E>
```

Here, `E` specifies the type of objects that the set will hold.

**TreeSet** has the following constructors:

- `TreeSet()`
- `TreeSet(Collection<? extends E> c)`
- `TreeSet(Comparator<? super E> comp)`
- `TreeSet(SortedSet<E> ss)`

The first form constructs an empty tree set that will be sorted in ascending order according to the natural order of its elements. The second form builds a tree set that contains the elements of `c`. The third form constructs an empty tree set that will be sorted according to the comparator specified by `comp`. (Comparators are described later in this chapter.) The fourth form builds a tree set that contains the elements of
Here is an example that demonstrates a TreeSet:

```java
// Demonstrate TreeSet.
import java.util.*;

class TreeSetDemo {
    public static void main(String args[]) {
        // Create a tree set.
        TreeSet<String> ts = new TreeSet<String>() {

            // Add elements to the tree set.
            ts.add("C");
            ts.add("A");
            ts.add("B");
            ts.add("E");
            ts.add("F");
            ts.add("D");

            System.out.println(ts);
        };
    }
}
```

The output from this program is shown here:

```
[A, B, C, D, E, F]
```

As explained, because TreeSet stores its elements in a tree, they are automatically arranged in sorted order, as the output confirms.

Because TreeSet implements the NavigableSet interface, you can use the methods defined by NavigableSet to retrieve elements of a TreeSet. For example, assuming the preceding program, the following statement uses subSet() to obtain a subset of ts that contains the elements between C (inclusive) and F (exclusive). It then displays the resulting set.

```java
System.out.println(ts.subSet("C", "F"));
```

The output from this statement is shown here:

```
[C, D, E]
```

You might want to experiment with the other methods defined by NavigableSet.
The PriorityQueue Class

PriorityQueue extends AbstractQueue and implements the Queue interface. It creates a queue that is prioritized based on the queue’s comparator. PriorityQueue is a generic class that has this declaration:

```
class PriorityQueue<E>
```

Here, E specifies the type of objects stored in the queue. PriorityQueues are dynamic, growing as necessary.

PriorityQueue defines the seven constructors shown here:

```
PriorityQueue()  
PriorityQueue(int capacity)  
PriorityQueue(Comparator<? super E> comp)  
PriorityQueue(int capacity, Comparator<? super E> comp)  
PriorityQueue(Collection<? extends E> c)  
PriorityQueue(PriorityQueue<? extends E> c)  
PriorityQueue(SortedSet<? extends E> c)
```

The first constructor builds an empty queue. Its starting capacity is 11. The second constructor builds a queue that has the specified initial capacity. The third constructor specifies a comparator, and the fourth builds a queue with the specified capacity and comparator. The last three constructors create queues that are initialized with the elements of the collection passed in c. In all cases, the capacity grows automatically as elements are added.

If no comparator is specified when a PriorityQueue is constructed, then the default comparator for the type of data stored in the queue is used. The default comparator will order the queue in ascending order. Thus, the head of the queue will be the smallest value. However, by providing a custom comparator, you can specify a different ordering scheme. For example, when storing items that include a time stamp, you could prioritize the queue such that the oldest items are first in the queue.

You can obtain a reference to the comparator used by a PriorityQueue by calling its comparator( ) method, shown here:

```
Comparator<? super E> comparator()
```

It returns the comparator. If natural ordering is used for the invoking queue, null is returned.

One word of caution: Although you can iterate through a PriorityQueue using an iterator, the order of that iteration is undefined. To properly use a PriorityQueue,
you must call methods such as `offer()` and `poll()`, which are defined by the `Queue` interface.

The ArrayDeque Class

The `ArrayDeque` class extends `AbstractCollection` and implements the `Deque` interface. It adds no methods of its own. `ArrayDeque` creates a dynamic array and has no capacity restrictions. (The `Deque` interface supports implementations that restrict capacity, but does not require such restrictions.) `ArrayDeque` is a generic class that has this declaration:

```java
class ArrayDeque<E>
```

Here, `E` specifies the type of objects stored in the collection.

`ArrayDeque` defines the following constructors:

```java
ArrayDeque( )
ArrayDeque(int size)
ArrayDeque(Collection<? extends E> c)
```

The first constructor builds an empty deque. Its starting capacity is 16. The second constructor builds a deque that has the specified initial capacity. The third constructor creates a deque that is initialized with the elements of the collection passed in `c`. In all cases, the capacity grows as needed to handle the elements added to the deque.

The following program demonstrates `ArrayDeque` by using it to create a stack:
The EnumSet Class

EnumSet extends AbstractSet and implements Set. It is specifically for use with elements of an enum type. It is a generic class that has this declaration:

```java
class EnumSet<E extends Enum<E>>
```

Here, E specifies the elements. Notice that E must extend Enum<E>, which enforces the requirement that the elements must be of the specified enum type.

EnumSet defines no constructors. Instead, it uses the factory methods shown in Table 19-7 to create objects. All methods can throw NullPointerException. The copyOf() and range() methods can also throw IllegalArgumentException. Notice that the of() method is overloaded a number of times. This is in the interest of efficiency. Passing a known number of arguments can be faster than using a vararg parameter when the number of arguments is small.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
</table>
| static `<E extends Enum<E>`
    EnumSet<E> allOf(Class<E> t) | Creates an `EnumSet` that contains the elements in the enumeration specified by `t`. |
| static `<E extends Enum<E>`
    EnumSet<E> complementOf(EnumSet<E> e) | Creates an `EnumSet` that is comprised of those elements not stored in `e`. |
| static `<E extends Enum<E>`
    EnumSet<E> copyOf(EnumSet<E> c) | Creates an `EnumSet` from the elements stored in `c`. |
| static `<E extends Enum<E>`
    EnumSet<E> copyOf(Collection<E> c) | Creates an `EnumSet` from the elements stored in `c`. |
| static `<E extends Enum<E>`
    EnumSet<E> noneOf(Class<E> t) | Creates an `EnumSet` that contains the elements that are not in the enumeration specified by `t`, which is an empty set by definition. |
| static `<E extends Enum<E>`
    EnumSet<E> of(E v, E ... varargs) | Creates an `EnumSet` that contains `v` and zero or more additional enumeration values. |
| static `<E extends Enum<E>`
    EnumSet<E> of(E v) | Creates an `EnumSet` that contains `v`. |
| static `<E extends Enum<E>`
    EnumSet<E> of(E v1, E v2) | Creates an `EnumSet` that contains `v1` and `v2`. |
| static `<E extends Enum<E>`
    EnumSet<E> of(E v1, E v2, E v3) | Creates an `EnumSet` that contains `v1` through `v3`. |
| static `<E extends Enum<E>`
    EnumSet<E> of(E v1, E v2, E v3, E v4) | Creates an `EnumSet` that contains `v1` through `v4`. |
| static `<E extends Enum<E>`
    EnumSet<E> of(E v1, E v2, E v3, E v4, E v5) | Creates an `EnumSet` that contains `v1` through `v5`. |
| static `<E extends Enum<E>`
    EnumSet<E> range(E start, E end) | Creates an `EnumSet` that contains the elements in the range specified by `start` and `end`. |

Table 19-7  The Methods Declared by `EnumSet`

**Accessing a Collection via an Iterator**

Often, you will want to cycle through the elements in a collection. For example, you might want to display each element. One way to do this is to employ an `iterator`, which is an object that implements either the `Iterator` or the `ListIterator` interface.
**Iterator** enables you to cycle through a collection, obtaining or removing elements. **ListIterator** extends **Iterator** to allow bidirectional traversal of a list, and the modification of elements. **Iterator** and **ListIterator** are generic interfaces which are declared as shown here:

```java
interface Iterator<E>
interface ListIterator<E>
```

Here, `E` specifies the type of objects being iterated. The **Iterator** interface declares the methods shown in **Table 19-8**. The methods declared by **ListIterator** (along with those inherited from **Iterator**) are shown in **Table 19-9**. In both cases, operations that modify the underlying collection are optional. For example, `remove()` will throw **UnsupportedOperationException** when used with a read-only collection. Various other exceptions are possible.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>default void forEachRemaining(Consumer&lt;? super E&gt; action)</td>
<td>The action specified by <code>action</code> is executed on each unprocessed element in the collection.</td>
</tr>
<tr>
<td>boolean hasNext()</td>
<td>Returns <code>true</code> if there are more elements. Otherwise, returns <code>false</code>.</td>
</tr>
<tr>
<td>E next()</td>
<td>Returns the next element. Throws <strong>NoSuchElementException</strong> if there is not a next element.</td>
</tr>
<tr>
<td>default void remove()</td>
<td>Removes the current element. Throws <strong>IllegalStateException</strong> if an attempt is made to call <code>remove()</code> that is not preceded by a call to <code>next()</code>. The default version throws an <strong>UnsupportedOperationException</strong>.</td>
</tr>
</tbody>
</table>

**Table 19-8** The Methods Declared by **Iterator**
Table 19-9  The Methods Provided by \texttt{ListIterator}

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>\texttt{void add(E \textit{obj})}</td>
<td>Inserts \textit{obj} into the list in front of the element that will be returned by the next call to \texttt{next().}</td>
</tr>
<tr>
<td>\texttt{default void forEachRemaining(}</td>
<td>The action specified by \textit{action} is executed on each unprocessed element in the collection.</td>
</tr>
<tr>
<td>\texttt{Consumer&lt;? super E&gt; action)}</td>
<td></td>
</tr>
<tr>
<td>\texttt{boolean hasNext()}</td>
<td>Returns \texttt{true} if there is a next element. Otherwise, returns \texttt{false.}</td>
</tr>
<tr>
<td>\texttt{boolean hasPrevious()}</td>
<td>Returns \texttt{true} if there is a previous element. Otherwise, returns \texttt{false.}</td>
</tr>
<tr>
<td>\texttt{E next()}</td>
<td>Returns the next element. A \texttt{NoSuchElementException} is thrown if there is not a next element.</td>
</tr>
<tr>
<td>\texttt{int nextIndex()}</td>
<td>Returns the index of the next element. If there is not a next element, returns the size of the list.</td>
</tr>
<tr>
<td>\texttt{E previous()}</td>
<td>Returns the previous element. A \texttt{NoSuchElementException} is thrown if there is not a previous element.</td>
</tr>
<tr>
<td>\texttt{int previousIndex()}</td>
<td>Returns the index of the previous element. If there is not a previous element, returns \texttt{-1.}</td>
</tr>
<tr>
<td>\texttt{void remove()}</td>
<td>Removes the current element from the list. An \texttt{IllegalStateException} is thrown if \texttt{remove()} is called before \texttt{next()} or \texttt{previous()} is invoked.</td>
</tr>
<tr>
<td>\texttt{void set(E \textit{obj})}</td>
<td>Assigns \textit{obj} to the current element. This is the element last returned by a call to either \texttt{next()} or \texttt{previous().}</td>
</tr>
</tbody>
</table>

\textbf{NOTE} Beginning with JDK 8, you can also use a \texttt{Spliterator} to cycle through a collection. \texttt{Spliterator} works differently than does \texttt{Iterator}, and it is described later in this chapter.

\section*{Using an Iterator}

Before you can access a collection through an iterator, you must obtain one. Each of the collection classes provides an \texttt{iterator()} method that returns an iterator to the start of the collection. By using this iterator object, you can access each element in the collection, one element at a time. In general, to use an iterator to cycle through the contents of a collection, follow these steps:
1. Obtain an iterator to the start of the collection by calling the collection’s \texttt{iterator()} method.

2. Set up a loop that makes a call to \texttt{hasNext()}. Have the loop iterate as long as \texttt{hasNext()} returns \texttt{true}.

3. Within the loop, obtain each element by calling \texttt{next()}.

For collections that implement \texttt{List}, you can also obtain an iterator by calling \texttt{listIterator()}. As explained, a list iterator gives you the ability to access the collection in either the forward or backward direction and lets you modify an element. Otherwise, \texttt{ListIterator} is used just like \texttt{Iterator}.

The following example implements these steps, demonstrating both the \texttt{Iterator} and \texttt{ListIterator} interfaces. It uses an \texttt{ArrayList} object, but the general principles apply to any type of collection. Of course, \texttt{ListIterator} is available only to those collections that implement the \texttt{List} interface.
// Demonstrate iterators.
import java.util.*;

class IteratorDemo {
    public static void main(String args[]) {
        // Create an array list.
        ArrayList<String> al = new ArrayList<String>();

        // Add elements to the array list.
        al.add("C");
        al.add("A");
        al.add("E");
        al.add("B");
        al.add("D");
        al.add("F");

        // Use iterator to display contents of al.
        System.out.print("Original contents of al: ");
        Iterator<String> itr = al.iterator();
        while(itr.hasNext()) {
            String element = itr.next();
            System.out.print(element + " ");
        }
        System.out.println();

        // Modify objects being iterated.
        ListIterator<String> litr = al.listIterator();
        while(litr.hasNext()) {
            String element = litr.next();
            litr.set(element + "+");
        }

        System.out.print("Modified contents of al: ");
        itr = al.iterator();
        while(itr.hasNext()) {
            String element = itr.next();
            System.out.print(element + " ");
        }
        System.out.println();

        // Now, display the list backwards.
        System.out.print("Modified list backwards: ");
        while(litr.hasPrevious()) {
            String element = litr.previous();
            System.out.print(element + " ");
        }
        System.out.println();
    }
}
Pay special attention to how the list is displayed in reverse. After the list is modified, \texttt{litr} points to the end of the list. (Remember, \texttt{litr.hasNext()} returns \texttt{false} when the end of the list has been reached.) To traverse the list in reverse, the program continues to use \texttt{litr}, but this time it checks to see whether it has a previous element. As long as it does, that element is obtained and displayed.

\textbf{The For-Each Alternative to Iterators}

If you won’t be modifying the contents of a collection or obtaining elements in reverse order, then the for-each version of the \texttt{for} loop is often a more convenient alternative to cycling through a collection than is using an iterator. Recall that the \texttt{for} can cycle through any collection of objects that implement the \texttt{Iterable} interface. Because all of the collection classes implement this interface, they can all be operated upon by the \texttt{for}.

The following example uses a \texttt{for} loop to sum the contents of a collection:
The output from the program is shown here:

```
Contents of vals: 1 2 3 4 5
Sum of values: 15
```

As you can see, the for loop is substantially shorter and simpler to use than the iterator-based approach. However, it can only be used to cycle through a collection in the forward direction, and you can’t modify the contents of the collection.

**Spliterator**

JDK 8 added a new type of iterator called a spliterator that is defined by the Spliterator interface. A spliterator cycles through a sequence of elements, and in
In this regard, it is similar to the iterators just described. However, the techniques required to use it differ. Furthermore, it offers substantially more functionality than does either `Iterator` or `ListIterator`. Perhaps the most important aspect of `Spliterator` is its ability to provide support for parallel iteration of portions of the sequence. Thus, `Spliterator` supports parallel programming. (See Chapter 28 for information on concurrency and parallel programming.) However, you can use `Spliterator` even if you won’t be using parallel execution. One reason you might want to do so is because it offers a streamlined approach that combines the `hasNext` and `next` operations into one method.

`Spliterator` is a generic interface that is declared like this:

```java
interface Spliterator<T>
```

Here, `T` is the type of elements being iterated. `Spliterator` declares the methods shown in Table 19-10.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>int characteristics( )</code></td>
<td>Returns the characteristics of the invoking spliterator, encoded into an integer.</td>
</tr>
<tr>
<td><code>long estimateSize( )</code></td>
<td>Estimates the number of elements left to iterate and returns the result. Returns <code>Long.MAX_VALUE</code> if the count cannot be obtained for any reason.</td>
</tr>
<tr>
<td><code>default void forEachRemaining( Consumer&lt;? super T&gt; action)</code></td>
<td>Applies <code>action</code> to each unprocessed element in the data source.</td>
</tr>
<tr>
<td><code>default Comparator&lt;? super T&gt; getComparator( )</code></td>
<td>Returns the comparator used by the invoking spliterator or <code>null</code> if natural ordering is used. If the sequence is unordered, <code>IllegalStateException</code> is thrown.</td>
</tr>
<tr>
<td><code>default long getExactSizeIfKnown( )</code></td>
<td>If the invoking spliterator is sized, returns the number of elements left to iterate. Returns <code>-1</code> otherwise.</td>
</tr>
<tr>
<td><code>default boolean hasCharacteristics(int val)</code></td>
<td>Returns <code>true</code> if the invoking spliterator has the characteristics passed in <code>val</code>. Returns <code>false</code> otherwise.</td>
</tr>
<tr>
<td><code>boolean tryAdvance( Consumer&lt;? super T&gt; action)</code></td>
<td>Executes <code>action</code> on the next element in the iteration. Returns <code>true</code> if there is a next element. Returns <code>false</code> if no elements remain.</td>
</tr>
<tr>
<td><code>Spliterator&lt;T&gt; trySplit( )</code></td>
<td>If possible, splits the invoking spliterator, returning a reference to a new spliterator for the partition. Otherwise, returns <code>null</code>. Thus, if successful, the original spliterator iterates over one portion of the sequence and the returned spliterator iterates over the other portion.</td>
</tr>
</tbody>
</table>
Using **Spliterator** for basic iteration tasks is quite easy: simply call **tryAdvance()** until it returns **false**. If you will be applying the same action to each element in the sequence, **forEachRemaining()** offers a streamlined alternative. In both cases, the action that will occur with each iteration is defined by what the **Consumer** object does with each element. **Consumer** is a functional interface that applies an action to an object. It is a generic functional interface declared in **java.util.function**. (See Chapter 20 for information on **java.util.function**.) **Consumer** specifies only one abstract method, **accept()**, which is shown here:

```java
void accept(T objRef)
```

In the case of **tryAdvance()**, each iteration passes the next element in the sequence to **objRef**. Often, the easiest way to implement **Consumer** is by use of a lambda expression.

The following program provides a simple example of **Spliterator**. Notice that the program demonstrates both **tryAdvance()** and **forEachRemaining()**. Also notice how these methods combine the actions of **Iterator**’s **next()** and **hasNext()** methods into a single call.

```java
// A simple Spliterator demonstration.
import java.util.*;

class SpliteratorDemo {
```
public static void main(String args[]) {
    // Create an array list for doubles.
    ArrayList<Double> vals = new ArrayList<>();

    // Add values to the array list.
    vals.add(1.0);
    vals.add(2.0);
    vals.add(3.0);
    vals.add(4.0);
    vals.add(5.0);

    // Use tryAdvance() to display contents of vals.
    System.out.print("Contents of vals:\n");
    Spliterator<Double> splititr = vals.spliterator();
    while(splititr.tryAdvance((n) -> System.out.println(n)));
    System.out.println();

    // Create new list that contains square roots.
    splititr = vals.spliterator();
    ArrayList<Double> sqrs = new ArrayList<>();
    while(splititr.tryAdvance((n) -> sqrs.add(Math.sqrt(n))));

    // Use forEachRemaining() to display contents of sqrs.
    System.out.print("Contents of sqrs:\n");
    splititr = sqrs.spliterator();
    splititr.forEachRemaining((n) -> System.out.println(n));
    System.out.println();
}

The output is shown here:
Contents of vals:
1.0
2.0
3.0
4.0
5.0

Contents of sqrs:
1.0
1.4142135623730951
1.7320508075688772
2.0
2.23606797749979

Although this program demonstrates the mechanics of using Spliterator, it does not reveal its full power. As mentioned, Spliterator’s maximum benefit is found in situations that involve parallel processing.

In Table 19-10, notice the methods characteristics( ) and hasCharacteristics( ). Each Spliterator has a set of attributes, called characteristics, associated with it. These are defined by static int fields in Spliterator, such as SORTED, DISTINCT, SIZED, and IMMUTABLE, to name a few. You can obtain the characteristics by calling characteristics( ). You can determine if a characteristic is present by calling hasCharacteristics( ). Often, you won’t need to access a Spliterator’s characteristics, but in some cases, they can aid in creating efficient, resilient code.

NOTE For a further discussion of Spliterator, see Chapter 29, where it is used in the context of the new stream API. For a discussion of lambda expressions, see Chapter 15. See Chapter 28 for a discussion of parallel programming and concurrency.

There are several nested subinterfaces of Spliterator designed for use with the primitive types double, int, and long. These are called Spliterator.OfDouble, Spliterator.OfInt, and Spliterator.OfLong. There is also a generalized version called Spliterator.OfPrimitive(), which offers additional flexibility and serves as a superinterface of the aforementioned ones.

Storing User-Defined Classes in Collections

For the sake of simplicity, the foregoing examples have stored built-in objects, such as String or Integer, in a collection. Of course, collections are not limited to the storage of built-in objects. Quite the contrary. The power of collections is that they can store any type of object, including objects of classes that you create. For
example, consider the following example that uses a LinkedList to store mailing addresses:
// A simple mailing list example.
import java.util.*;

class Address {
    private String name;
    private String street;
    private String city;
    private String state;
    private String code;

    Address(String n, String s, String c,
        String st, String cd) {
        name = n;
        street = s;
        city = c;
        state = st;
        code = cd;
    }

    public String toString() {
        return name + "\n" + street + "\n" +
        city + " " + state + " " + code;
    }
}

class MailList {
    public static void main(String args[]) {
        LinkedList<Address> ml = new LinkedList<Address>();

        // Add elements to the linked list.
        ml.add(new Address("J.W. West", "11 Oak Ave",
            "Urbana", "IL", "61801");
        ml.add(new Address("Ralph Baker", "1142 Maple Lane",
            "Mahomet", "IL", "61853");
        ml.add(new Address("Tom Carlton", "867 Elm St",
            "Champaign", "IL", "61820");

        // Display the mailing list.
        for(Address element : ml)
            System.out.println(element + "\n");

        System.out.println();
    }
}
The output from the program is shown here:

J.W. West
11 Oak Ave
Urbana IL 61801

Ralph Baker
1142 Maple Lane
Mahomet IL 61853

Tom Carlton
867 Elm St
Champaign IL 61820

Aside from storing a user-defined class in a collection, another important thing to notice about the preceding program is that it is quite short. When you consider that it sets up a linked list that can store, retrieve, and process mailing addresses in about 50 lines of code, the power of the Collections Framework begins to become apparent. As most readers know, if all of this functionality had to be coded manually, the program would be several times longer. Collections offer off-the-shelf solutions to a wide variety of programming problems. You should use them whenever the situation presents itself.

The RandomAccess Interface

The RandomAccess interface contains no members. However, by implementing this interface, a collection signals that it supports efficient random access to its elements. Although a collection might support random access, it might not do so efficiently. By checking for the RandomAccess interface, client code can determine at run time whether a collection is suitable for certain types of random access operations—especially as they apply to large collections. (You can use instanceof to determine if a class implements an interface.) RandomAccess is implemented by ArrayList and by the legacy Vector class, among others.

Working with Maps

A map is an object that stores associations between keys and values, or key/value pairs. Given a key, you can find its value. Both keys and values are objects. The keys must be unique, but the values may be duplicated. Some maps can accept a null key and null values, others cannot.
There is one key point about maps that is important to mention at the outset: they don’t implement the `Iterable` interface. This means that you cannot cycle through a map using a for-each style `for` loop. Furthermore, you can’t obtain an iterator to a map. However, as you will soon see, you can obtain a collection-view of a map, which does allow the use of either the `for` loop or an iterator.

The Map Interfaces

Because the map interfaces define the character and nature of maps, this discussion of maps begins with them. The following interfaces support maps:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map</td>
<td>Maps unique keys to values.</td>
</tr>
<tr>
<td>Map.Entry</td>
<td>Describes an element (a key/value pair) in a map. This is an inner class of Map.</td>
</tr>
<tr>
<td>NavigableMap</td>
<td>Extends <code>SortedMap</code> to handle the retrieval of entries based on closest-match searches.</td>
</tr>
<tr>
<td>SortedMap</td>
<td>Extends <code>Map</code> so that the keys are maintained in ascending order.</td>
</tr>
</tbody>
</table>

Each interface is examined next, in turn.

The Map Interface

The `Map` interface maps unique keys to values. A `key` is an object that you use to retrieve a value at a later date. Given a key and a value, you can store the value in a `Map` object. After the value is stored, you can retrieve it by using its key. `Map` is generic and is declared as shown here:

```java
interface Map<K, V>
```

Here, `K` specifies the type of keys, and `V` specifies the type of values.

The methods declared by `Map` are summarized in Table 19-11. Several methods throw a `ClassCastException` when an object is incompatible with the elements in a map. A `NullPointerException` is thrown if an attempt is made to use a `null` object and `null` is not allowed in the map. An `UnsupportedOperationException` is thrown when an attempt is made to change an unmodifiable map. An `IllegalArgumentException` is thrown if an invalid argument is used.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void clear()</td>
<td>Removes all key/value pairs from the invoking map.</td>
</tr>
<tr>
<td>default V compute(K k, BiFunction&lt;? super K, ? super V, ? extends V&gt; func)</td>
<td>Calls <code>func</code> to construct a new value. If <code>func</code> returns non-null, the new key/value pair is added to the map, any preexisting pairing is removed, and the new value is returned. If <code>func</code> returns null, any preexisting pairing is removed, and null is returned.</td>
</tr>
<tr>
<td>default V computeIfAbsent(K k, Function&lt;? super K, ? extends V&gt; func)</td>
<td>Returns the value associated with the key <code>k</code>. Otherwise, the value is constructed through a call to <code>func</code> and the pairing is entered into the map and the constructed value is returned. If no value can be constructed, null is returned.</td>
</tr>
<tr>
<td>default V computeIfPresent(K k, BiFunction&lt;? super K, ? super V, ? extends V&gt; func)</td>
<td>If <code>k</code> is in the map, a new value is constructed through a call to <code>func</code> and the new value replaces the old value in the map. In this case, the new value is returned. If the value returned by <code>func</code> is null, the existing key and value are removed from the map and null is returned.</td>
</tr>
<tr>
<td>boolean containsKey(Object k)</td>
<td>Returns true if the invoking map contains <code>k</code> as a key. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean containsValue(Object v)</td>
<td>Returns true if the map contains <code>v</code> as a value. Otherwise, returns false.</td>
</tr>
<tr>
<td>static &lt;K, V&gt; Map.Entry&lt;K, V&gt; entry(K k, V v)</td>
<td>Returns an unmodifiable map entry comprised of the specified key and value. A null key or value is not allowed. (Added by JDK 9.)</td>
</tr>
<tr>
<td>Set&lt;Map.Entry&lt;K, V&gt;&gt; entrySet()</td>
<td>Returns a Set that contains the entries in the map. The set contains objects of type Map.Entry. Thus, this method provides a set-view of the invoking map.</td>
</tr>
<tr>
<td>boolean equals(Object obj)</td>
<td>Returns true if <code>obj</code> is a Map and contains the same entries. Otherwise, returns false.</td>
</tr>
<tr>
<td>default void forEach(BiConsumer&lt;? super K, ? super V&gt; action)</td>
<td>Executes action on each element in the invoking map. A ConcurrentModificationException will be thrown if an element is removed during the process.</td>
</tr>
<tr>
<td>V get(Object k)</td>
<td>Returns the value associated with the key <code>k</code>. Returns null if the key is not found.</td>
</tr>
<tr>
<td>default V getOrDefault(Object k, V defVal)</td>
<td>Returns the value associated with <code>k</code> if it is in the map. Otherwise, <code>defVal</code> is returned.</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns the hash code for the invoking map.</td>
</tr>
<tr>
<td>boolean isEmpty()</td>
<td>Returns true if the invoking map is empty. Otherwise, returns false.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td><code>Set&lt;K&gt; keySet()</code></td>
<td>Returns a <code>Set</code> that contains the keys in the invoking map. This method provides a set-view of the keys in the invoking map.</td>
</tr>
<tr>
<td><code>default V merge(K k, V v, BiFunction&lt;? super V, ? super V, ? extends V&gt; func)</code></td>
<td>If <code>k</code> is not in the map, the pairing <code>k,v</code> is added to the map. In this case, <code>v</code> is returned. Otherwise, <code>func</code> returns a new value based on the old value, the key is updated to use this value, and <code>merge()</code> returns this value. If the value returned by <code>func</code> is <code>null</code>, the existing key and value are removed from the map and <code>null</code> is returned.</td>
</tr>
<tr>
<td><code>static &lt;K, V&gt; Map&lt;K, V&gt; of( parameter-list )</code></td>
<td>Creates an unmodifiable map containing the entries specified in <code>parameter-list</code>. Null keys or values are not allowed. Many overloaded versions are provided. See the discussion in the text for details. (Added by JDK 9.)</td>
</tr>
<tr>
<td><code>static &lt;K, V&gt; Map&lt;K, V&gt;</code></td>
<td>Returns an unmodifiable map that contains the key/value mappings described by the entries passed in <code>entries</code>. Null keys or values are not allowed. (Added by JDK 9.)</td>
</tr>
<tr>
<td><code>V put(K k, V v)</code></td>
<td>Puts an entry in the invoking map, overwriting any previous value associated with the key. The key and value are <code>k</code> and <code>v</code>, respectively. Returns <code>null</code> if the key did not already exist. Otherwise, the previous value linked to the key is returned.</td>
</tr>
<tr>
<td><code>void putAll(Map&lt;? extends K, ? extends V&gt; m)</code></td>
<td>Puts all the entries from <code>m</code> into this map.</td>
</tr>
<tr>
<td><code>default V putIfAbsent( K k, V v)</code></td>
<td>Inserts the key/value pair into the invoking map if this pairing is not already present or if the existing value is <code>null</code>. Returns the old value. The <code>null</code> value is returned when no previous mapping exists, or the value is <code>null</code>.</td>
</tr>
<tr>
<td><code>V remove(Object k)</code></td>
<td>Removes the entry whose key equals <code>k</code>.</td>
</tr>
<tr>
<td><code>default boolean remove(Object k, Object v)</code></td>
<td>If the key/value pair specified by <code>k</code> and <code>v</code> is in the invoking map, it is removed and <code>true</code> is returned. Otherwise, <code>false</code> is returned.</td>
</tr>
<tr>
<td><code>default boolean replace(K k, V oldV, V newV)</code></td>
<td>If the key/value pair specified by <code>k</code> and <code>oldV</code> is in the invoking map, the value is replaced by <code>newV</code> and <code>true</code> is returned. Otherwise <code>false</code> is returned.</td>
</tr>
<tr>
<td><code>default V replace(K k, V v)</code></td>
<td>If the key specified by <code>k</code> is in the invoking map, its value is set to <code>v</code> and the previous value is returned. Otherwise, <code>null</code> is returned.</td>
</tr>
<tr>
<td><code>default void replaceAll(BiFunction&lt;? super K, ? super V, ? extends V&gt; func)</code></td>
<td>Executes <code>func</code> on each element of the invoking map, replacing the element with the result returned by <code>func</code>. A <code>ConcurrentModificationException</code> will be thrown if an element is removed during the process.</td>
</tr>
</tbody>
</table>
Maps revolve around two basic operations: `get()` and `put()`. To put a value into a map, use `put()`, specifying the key and the value. To obtain a value, call `get()`, passing the key as an argument. The value is returned.

As mentioned earlier, although part of the Collections Framework, maps are not, themselves, collections because they do not implement the `Collection` interface. However, you can obtain a collection-view of a map. To do this, you can use the `entrySet()` method. It returns a `Set` that contains the elements in the map. To obtain a collection-view of the keys, use `keySet()`. To get a collection-view of the values, use `values()`. For all three collection-views, the collection is backed by the map. Changing one affects the other. Collection-views are the means by which maps are integrated into the larger Collections Framework.

Beginning with JDK 9, `Map` includes the `of()` factory method, which has a number of overloads. Each version returns an unmodifiable, value-based map that is comprised of the arguments that it is passed. The primary purpose of `of()` is to provide a convenient, efficient way to create a small `Map`. There are 11 overloads of `of()`. One takes no arguments and creates an empty map. It is shown here:

```java
static <K, V> Map<K, V> of()
```

Ten overloads take from 1 to 10 arguments and create a list that contains the specified elements. They are shown here:

```java
static <K, V> Map<K, V> of(K k1, V v1)
static <K, V> Map<K, V> of(K k1, V v1, K k2, V v2)
static <K, V> Map<K, V> of(K k1, V v1, K k2, V v2, K k3, V v3)
...
static <K, V> Map<K, V> of(K k1, V v1, K k2, V v2, K k3, V v3, K k4, V v4, K k5, V v5, K k6, V v6, K k7, V v7, K k8, V v8, K k9, V v9, K k10, V v10)
```

For all versions, `null` keys and/or values are not allowed. In all cases, the `Map` implementation is unspecified.

### The SortedMap Interface
The SortedMap interface extends Map. It ensures that the entries are maintained in ascending order based on the keys. SortedMap is generic and is declared as shown here:

```java
interface SortedMap<K, V>
```

Here, K specifies the type of keys, and V specifies the type of values.

The methods declared by SortedMap are summarized in Table 19-12. Several methods throw a NoSuchElementException when no items are in the invoking map. A ClassCastException is thrown when an object is incompatible with the elements in a map. A NullPointerException is thrown if an attempt is made to use a null object when null is not allowed in the map. An IllegalArgumentException is thrown if an invalid argument is used.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparator&lt;? super K&gt; comparator()</td>
<td>Returns the invoking sorted map's comparator. If natural ordering is used for the invoking map, null is returned.</td>
</tr>
<tr>
<td>K firstKey()</td>
<td>Returns the first key in the invoking map.</td>
</tr>
<tr>
<td>SortedMap&lt;K, V&gt; headMap(K end)</td>
<td>Returns a sorted map for those map entries with keys that are less than end.</td>
</tr>
<tr>
<td>K lastKey()</td>
<td>Returns the last key in the invoking map.</td>
</tr>
<tr>
<td>SortedMap&lt;K, V&gt; subMap(K start, K end)</td>
<td>Returns a map containing those entries with keys that are greater than or equal to start and less than end.</td>
</tr>
<tr>
<td>SortedMap&lt;K, V&gt; tailMap(K start)</td>
<td>Returns a map containing those entries with keys that are greater than or equal to start.</td>
</tr>
</tbody>
</table>

Table 19-12  The Methods Declared by SortedMap

Sorted maps allow very efficient manipulations of submaps (in other words, subsets of a map). To obtain a submap, use headMap(), tailMap(), or subMap(). The submap returned by these methods is backed by the invoking map. Changing one changes the other. To get the first key in the set, call firstKey(). To get the last key, use lastKey().

The NavigableMap Interface

The NavigableMap interface extends SortedMap and declares the behavior of a map that supports the retrieval of entries based on the closest match to a given key or keys. NavigableMap is a generic interface that has this declaration:

```java
interface NavigableMap<K,V>
```
Here, K specifies the type of the keys, and V specifies the type of the values associated with the keys. In addition to the methods that it inherits from SortedMap, NavigableMap adds those summarized in Table 19-13. Several methods throw a ClassCastException when an object is incompatible with the keys in the map. A NullPointerException is thrown if an attempt is made to use a null object and null keys are not allowed in the set. An IllegalArgumentException is thrown if an invalid argument is used.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>Map.Entry&lt;K,V&gt; ceilingEntry(K obj)</code></td>
<td>Searches the map for the smallest key <code>k</code> such that <code>k &gt;= obj</code>. If such a key is found, its entry is returned. Otherwise, <code>null</code> is returned.</td>
</tr>
<tr>
<td><code>K ceilingKey(K obj)</code></td>
<td>Searches the map for the smallest key <code>k</code> such that <code>k &gt;= obj</code>. If such a key is found, it is returned. Otherwise, <code>null</code> is returned.</td>
</tr>
<tr>
<td><code>NavigableSet&lt;K&gt; descendingKeySet()</code></td>
<td>Returns a <code>NavigableSet</code> that contains the keys in the invoking map in reverse order. Thus, it returns a reverse set-view of the keys. The resulting set is backed by the map.</td>
</tr>
<tr>
<td><code>NavigableMap&lt;K,V&gt; descendingMap()</code></td>
<td>Returns a <code>NavigableMap</code> that is the reverse of the invoking map. The resulting map is backed by the invoking map.</td>
</tr>
<tr>
<td><code>Map.Entry&lt;K,V&gt; firstEntry()</code></td>
<td>Returns the first entry in the map. This is the entry with the least key.</td>
</tr>
<tr>
<td><code>Map.Entry&lt;K,V&gt; floorEntry(K obj)</code></td>
<td>Searches the map for the largest key <code>k</code> such that <code>k &lt;= obj</code>. If such a key is found, its entry is returned. Otherwise, <code>null</code> is returned.</td>
</tr>
<tr>
<td><code>K floorKey(K obj)</code></td>
<td>Searches the map for the largest key <code>k</code> such that <code>k &lt;= obj</code>. If such a key is found, it is returned. Otherwise, <code>null</code> is returned.</td>
</tr>
<tr>
<td><code>NavigableMap&lt;K,V&gt; headMap(K upperBound, boolean incl)</code></td>
<td>Returns a <code>NavigableMap</code> that includes all entries from the invoking map that have keys that are less than <code>upperBound</code>. If <code>incl</code> is <code>true</code>, then an element equal to <code>upperBound</code> is included. The resulting map is backed by the invoking map.</td>
</tr>
<tr>
<td><code>Map.Entry&lt;K,V&gt; higherEntry(K obj)</code></td>
<td>Searches the set for the largest key <code>k</code> such that <code>k &gt; obj</code>. If such a key is found, its entry is returned. Otherwise, <code>null</code> is returned.</td>
</tr>
<tr>
<td><code>K higherKey(K obj)</code></td>
<td>Searches the set for the largest key <code>k</code> such that <code>k &gt; obj</code>. If such a key is found, it is returned. Otherwise, <code>null</code> is returned.</td>
</tr>
<tr>
<td><code>Map.Entry&lt;K,V&gt; lastEntry()</code></td>
<td>Returns the last entry in the map. This is the entry with the largest key.</td>
</tr>
<tr>
<td><code>Map.Entry&lt;K,V&gt; lowerEntry(K obj)</code></td>
<td>Searches the set for the largest key <code>k</code> such that <code>k &lt; obj</code>. If such a key is found, its entry is returned. Otherwise, <code>null</code> is returned.</td>
</tr>
<tr>
<td><code>K lowerKey(K obj)</code></td>
<td>Searches the set for the largest key <code>k</code> such that <code>k &lt; obj</code>. If such a key is found, it is returned. Otherwise, <code>null</code> is returned.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>NavigableSet(&lt;K&gt;) navigableKeySet()</td>
<td>Returns a NavigableSet that contains the keys in the invoking map. The resulting set is backed by the invoking map.</td>
</tr>
<tr>
<td>Map.Entry(&lt;K,V&gt;) pollFirstEntry()</td>
<td>Returns the first entry, removing the entry in the process. Because the map is sorted, this is the entry with the least key value. null is returned if the map is empty.</td>
</tr>
<tr>
<td>Map.Entry(&lt;K,V&gt;) pollLastEntry()</td>
<td>Returns the last entry, removing the entry in the process. Because the map is sorted, this is the entry with the greatest key value. null is returned if the map is empty.</td>
</tr>
<tr>
<td>NavigableMap(&lt;K,V&gt;) subMap(K lowerBound,</td>
<td>Returns a NavigableMap that includes all entries from the invoking map that have keys that are greater than lowerBound and less than upperBound. If lowIncl is true, then an element equal to lowerBound is included. If highIncl is true, then an element equal to highIncl is included. The resulting map is backed by the invoking map.</td>
</tr>
<tr>
<td>boolean lowIncl, K upperBound</td>
<td></td>
</tr>
<tr>
<td>boolean highIncl)</td>
<td></td>
</tr>
<tr>
<td>NavigableMap(&lt;K,V&gt;) tailMap(K lowerBound,</td>
<td>Returns a NavigableMap that includes all entries from the invoking map that have keys that are greater than lowerBound. If incl is true, then an element equal to lowerBound is included. The resulting map is backed by the invoking map.</td>
</tr>
<tr>
<td>boolean incl)</td>
<td></td>
</tr>
</tbody>
</table>

Table 19-13  The Methods Declared by NavigableMap

The Map.Entry Interface

The Map.Entry interface enables you to work with a map entry. For example, recall that the entrySet() method declared by the Map interface returns a Set containing the map entries. Each of these set elements is a Map.Entry object. Map.Entry is generic and is declared like this:

    interface Map.Entry\(<K, V>\>

Here, K specifies the type of keys, and V specifies the type of values. Table 19-14 summarizes the non-static methods declared by Map.Entry. It also has two static methods. The first is comparingByKey(), which returns a Comparator that compares entries by key. The second is comparingByValue(), which returns a Comparator that compares entries by value.
Table 19-14 The Non-Static Methods Declared by `Map.Entry`

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean equals(Object obj)</td>
<td>Returns true if obj is a <code>Map.Entry</code> whose key and value are equal to that of the invoking object.</td>
</tr>
<tr>
<td>K getKey()</td>
<td>Returns the key for this map entry.</td>
</tr>
<tr>
<td>V getValue()</td>
<td>Returns the value for this map entry.</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns the hash code for this map entry.</td>
</tr>
<tr>
<td>V setValue(V v)</td>
<td>Sets the value for this map entry to v. A <code>ClassCastException</code> is thrown if v is not the correct type for the map. An <code>IllegalArgumentException</code> is thrown if there is a problem with v. A <code>NullPointerException</code> is thrown if v is null and the map does not permit null keys. An <code>UnsupportedOperationException</code> is thrown if the map cannot be changed.</td>
</tr>
</tbody>
</table>

The Map Classes

Several classes provide implementations of the map interfaces. The classes that can be used for maps are summarized here:

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AbstractMap</td>
<td>Implements most of the <code>Map</code> interface.</td>
</tr>
<tr>
<td>EnumMap</td>
<td>Extends <code>AbstractMap</code> for use with enum keys.</td>
</tr>
<tr>
<td>HashMap</td>
<td>Extends <code>AbstractMap</code> to use a hash table.</td>
</tr>
<tr>
<td>TreeMap</td>
<td>Extends <code>AbstractMap</code> to use a tree.</td>
</tr>
<tr>
<td>WeakHashMap</td>
<td>Extends <code>AbstractMap</code> to use a hash table with weak keys.</td>
</tr>
<tr>
<td>LinkedHashMap</td>
<td>Extends <code>HashMap</code> to allow insertion-order iterations.</td>
</tr>
<tr>
<td>IdentityHashMap</td>
<td>Extends <code>AbstractMap</code> and uses reference equality when comparing documents.</td>
</tr>
</tbody>
</table>

Notice that `AbstractMap` is a superclass for all concrete map implementations. `WeakHashMap` implements a map that uses “weak keys,” which allows an element in a map to be garbage-collected when its key is otherwise unused. This class is not discussed further here. The other map classes are described next.

The HashMap Class
The **HashMap** class extends **AbstractMap** and implements the **Map** interface. It uses a hash table to store the map. This allows the execution time of **get( )** and **put( )** to remain constant even for large sets. **HashMap** is a generic class that has this declaration:

```
class HashMap<K, V>
```

Here, **K** specifies the type of keys, and **V** specifies the type of values.

The following constructors are defined:

```
HashMap( )
HashMap(Map<? extends K, ? extends V> m)
HashMap(int capacity)
HashMap(int capacity, float fillRatio)
```

The first form constructs a default hash map. The second form initializes the hash map by using the elements of **m**. The third form initializes the capacity of the hash map to **capacity**. The fourth form initializes both the capacity and fill ratio of the hash map by using its arguments. The meaning of capacity and fill ratio is the same as for **HashSet**, described earlier. The default capacity is 16. The default fill ratio is 0.75.

**HashMap** implements **Map** and extends **AbstractMap**. It does not add any methods of its own.

You should note that a hash map does not guarantee the order of its elements. Therefore, the order in which elements are added to a hash map is not necessarily the order in which they are read by an iterator.

The following program illustrates **HashMap**. It maps names to account balances. Notice how a set-view is obtained and used.
import java.util.*;

class HashMapDemo {
    public static void main(String args[]) {

        // Create a hash map.
        HashMap<String, Double> hm = new HashMap<String, Double>();

        // Put elements to the map
        hm.put("John Doe", 3434.34);
        hm.put("Tom Smith", 123.22);
        hm.put("Jane Baker", 1378.00);
        hm.put("Tod Hall", 99.22);
        hm.put("Ralph Smith", -19.08);

        // Get a set of the entries.
        Set<Map.Entry<String, Double>> set = hm.entrySet();

        // Display the set.
        for(Map.Entry<String, Double> me : set) {
            System.out.print(me.getKey() + " : ");
            System.out.println(me.getValue());
        }
        System.out.println();

        // Deposit 1000 into John Doe's account.
        double balance = hm.get("John Doe");
        hm.put("John Doe", balance + 1000);

        System.out.println("John Doe's new balance: " +
         hm.get("John Doe"));
    }
}

Output from this program is shown here (the precise order may vary):

Ralph Smith: -19.08
Tom Smith: 123.22
John Doe: 3434.34
Tod Hall: 99.22
Jane Baker: 1378.0

John Doe's new balance: 4434.34
The program begins by creating a hash map and then adds the mapping of names to balances. Next, the contents of the map are displayed by using a set-view, obtained by calling `entrySet()` . The keys and values are displayed by calling the `getKey()` and `getValue()` methods that are defined by `Map.Entry` . Pay close attention to how the deposit is made into John Doe’s account. The `put()` method automatically replaces any preexisting value that is associated with the specified key with the new value. Thus, after John Doe’s account is updated, the hash map will still contain just one "John Doe" account.

The TreeMap Class

The `TreeMap` class extends `AbstractMap` and implements the `NavigableMap` interface. It creates maps stored in a tree structure. A `TreeMap` provides an efficient means of storing key/value pairs in sorted order and allows rapid retrieval. You should note that, unlike a hash map, a tree map guarantees that its elements will be sorted in ascending key order. `TreeMap` is a generic class that has this declaration:

```java
class TreeMap<K, V>
```

Here, `K` specifies the type of keys, and `V` specifies the type of values.

The following `TreeMap` constructors are defined:

```java
TreeMap( )
TreeMap(Comparator<? super K> comp)
TreeMap(Map<? extends K, ? extends V> m)
TreeMap(SortedMap<K, ? extends V> sm)
```

The first form constructs an empty tree map that will be sorted by using the natural order of its keys. The second form constructs an empty tree-based map that will be sorted by using the `Comparator comp` . (Comparators are discussed later in this chapter.) The third form initializes a tree map with the entries from `m` , which will be sorted by using the natural order of the keys. The fourth form initializes a tree map with the entries from `sm` , which will be sorted in the same order as `sm` .

`TreeMap` has no map methods beyond those specified by the `NavigableMap` interface and the `AbstractMap` class.

The following program reworks the preceding example so that it uses `TreeMap` :
import java.util.*;

class TreeMapDemo {
    public static void main(String args[]) {

        // Create a tree map.
        TreeMap<String, Double> tm = new TreeMap<String, Double>();

        // Put elements to the map.
        tm.put("John Doe", 3434.34);
        tm.put("Tom Smith", 123.22);
        tm.put("Jane Baker", 1378.00);
        tm.put("Tod Hall", 99.22);
        tm.put("Ralph Smith", -19.08);

        // Get a set of the entries.
        Set<Map.Entry<String, Double>> set = tm.entrySet();

        // Display the elements.
        for (Map.Entry<String, Double> me : set) {
            System.out.print(me.getKey() + " : ");
            System.out.println(me.getValue());
        }
        System.out.println();

        // Deposit 1000 into John Doe's account.
        double balance = tm.get("John Doe");
        tm.put("John Doe", balance + 1000);

        System.out.println("John Doe's new balance: " +
        tm.get("John Doe"));
    }
}

The following is the output from this program:

Jane Baker: 1378.0
John Doe: 3434.34
Ralph Smith: -19.08
Todd Hall: 99.22
Tom Smith: 123.22

John Doe's current balance: 4434.34
Notice that TreeMap sorts the keys. However, in this case, they are sorted by first name instead of last name. You can alter this behavior by specifying a comparator when the map is created, as described shortly.

The LinkedHashSet Class

LinkedHashSet extends HashSet. It maintains a linked list of the entries in the map, in the order in which they were inserted. This allows insertion-order iteration over the map. That is, when iterating through a collection-view of a LinkedHashSet, the elements will be returned in the order in which they were inserted. You can also create a LinkedHashSet that returns its elements in the order in which they were last accessed. LinkedHashSet is a generic class that has this declaration:

    class LinkedHashSet<K, V>

Here, K specifies the type of keys, and V specifies the type of values.

LinkedHashSet defines the following constructors:

- LinkedHashSet()
- LinkedHashSet(Map<? extends K, ? extends V> m)
- LinkedHashSet(int capacity)
- LinkedHashSet(int capacity, float fillRatio)
- LinkedHashSet(int capacity, float fillRatio, boolean Order)

The first form constructs a default LinkedHashSet. The second form initializes the LinkedHashSet with the elements from m. The third form initializes the capacity. The fourth form initializes both capacity and fill ratio. The meaning of capacity and fill ratio are the same as for HashMap. The default capacity is 16. The default ratio is 0.75. The last form allows you to specify whether the elements will be stored in the linked list by insertion order, or by order of last access. If Order is true, then access order is used. If Order is false, then insertion order is used.

LinkedHashSet adds only one method to those defined by HashMap. This method is removeEldestEntry(), and it is shown here:

    protected boolean removeEldestEntry(Map.Entry<K, V> e)

This method is called by put() and putAll(). The oldest entry is passed in e. By default, this method returns false and does nothing. However, if you override this method, then you can have the LinkedHashSet remove the oldest entry in the map. To do this, have your override return true. To keep the oldest entry, return false.
The IdentityHashMap Class

IdentityHashMap extends AbstractMap and implements the Map interface. It is similar to HashMap except that it uses reference equality when comparing elements. IdentityHashMap is a generic class that has this declaration:

class IdentityHashMap<K, V>

Here, K specifies the type of key, and V specifies the type of value. The API documentation explicitly states that IdentityHashMap is not for general use.

The EnumMap Class

EnumMap extends AbstractMap and implements Map. It is specifically for use with keys of an enum type. It is a generic class that has this declaration:

class EnumMap<K extends Enum<K>, V>

Here, K specifies the type of key, and V specifies the type of value. Notice that K must extend Enum<K>, which enforces the requirement that the keys must be of an enum type.

EnumMap defines the following constructors:

EnumMap(Class<K> kType)
EnumMap(Map<K, ? extends V> m)
EnumMap(EnumMap<K, ? extends V> em)

The first constructor creates an empty EnumMap of type kType. The second creates an EnumMap map that contains the same entries as m. The third creates an EnumMap initialized with the values in em.

EnumMap defines no methods of its own.

Comparators

Both TreeSet and TreeMap store elements in sorted order. However, it is the comparator that defines precisely what “sorted order” means. By default, these classes store their elements by using what Java refers to as “natural ordering,” which is usually the ordering that you would expect (A before B, 1 before 2, and so forth). If you want to order elements a different way, then specify a Comparator when you construct the set or map. Doing so gives you the ability to govern precisely how elements are stored within sorted collections and maps.

Comparator is a generic interface that has this declaration:

interface Comparator<T>

Here, T specifies the type of objects being compared.
Prior to JDK 8, the `Comparator` interface defined only two methods: `compare()` and `equals()`. The `compare()` method, shown here, compares two elements for order:

```java
int compare(T obj1, T obj2)
```

`obj1` and `obj2` are the objects to be compared. Normally, this method returns zero if the objects are equal. It returns a positive value if `obj1` is greater than `obj2`. Otherwise, a negative value is returned. The method can throw a `ClassCastException` if the types of the objects are not compatible for comparison.

By implementing `compare()`, you can alter the way that objects are ordered. For example, to sort in reverse order, you can create a comparator that reverses the outcome of a comparison.

The `equals()` method, shown here, tests whether an object equals the invoking comparator:

```java
boolean equals(object obj)
```

Here, `obj` is the object to be tested for equality. The method returns `true` if `obj` and the invoking object are both `Comparator` objects and use the same ordering. Otherwise, it returns `false`. Overriding `equals()` is not necessary, and most simple comparators will not do so.

For many years, the preceding two methods were the only methods defined by `Comparator`. With the release of JDK 8, the situation dramatically changed. JDK 8 added significant new functionality to `Comparator` through the use of default and static interface methods. Each is described here.

You can obtain a comparator that reverses the ordering of the comparator on which it is called by using `reversed()`, shown here:

```java
default Comparator<T> reversed()
```

It returns the reverse comparator. For example, assuming a comparator that uses natural ordering for the characters A through Z, a reverse order comparator would put B before A, C before B, and so on.

A method related to `reversed()` is `reverseOrder()`, shown next:

```java
static <T extends Comparable<? super T>> Comparator<T> reverseOrder()
```

It returns a comparator that reverses the natural order of the elements. Conversely, you can obtain a comparator that uses natural ordering by calling the static method `naturalOrder()`, shown next:

```java
static <T extends Comparable<? super T>> Comparator<T> naturalOrder()
```

If you want a comparator that can handle `null` values, use `nullsFirst()` or `nullsLast()`, shown here:

```java
static <T> Comparator<T> nullsFirst(Comparator<? super T> comp)
```

```java
static <T> Comparator<T> nullsLast(Comparator<? super T> comp)
```
static <T> Comparator<T> nullsLast(Comparator<? super T> comp)

The **nullsFirst( )** method returns a comparator that views **null** values as less than other values. The **nullsLast( )** method returns a comparator that views **null** values as greater than other values. In both cases, if the two values being compared are non-null, **comp** performs the comparison. If **comp** is passed **null**, then all non-null values are viewed as equivalent.

Another default method is **thenComparing( )**. It returns a comparator that performs a second comparison when the outcome of the first comparison indicates that the objects being compared are equal. Thus, it can be used to create a “compare by X then compare by Y” sequence. For example, when comparing cities, the first comparison might compare names, with the second comparison comparing states. (Therefore, Springfield, Illinois, would come before Springfield, Missouri, assuming normal, alphabetical order.)

The **thenComparing( )** method has three forms. The first, shown here, lets you specify the second comparator by passing an instance of **Comparator**:

```
default Comparator<T> thenComparing(Comparator<? super T> thenByComp)
```

Here, **thenByComp** specifies the comparator that is called if the first comparison returns equal.

The next versions of **thenComparing( )** let you specify the standard functional interface **Function** (defined by **java.util.function**). They are shown here:

```
default <U extends Comparable<? super U> Comparator<T> thenComparing(Function<? super T, ? extends U> getKey)

default <U> Comparator<T> thenComparing(Function<? super T, ? extends U> getKey, Comparator<? super U> keyComp)
```

In both, **getKey** refers to function that obtains the next comparison key, which is used if the first comparison returns equal. In the second version, **keyComp** specifies the comparator used to compare keys. (Here, and in subsequent uses, **U** specifies the type of the key.)

**Comparator** also adds the following specialized versions of “then comparing” methods for the primitive types:

```
default Comparator<T> thenComparingDouble(ToDoubleFunction<? super T> getKey)

default Comparator<T> thenComparingInt(ToIntFunction<? super T> getKey)
```
default Comparator<T>
    thenComparingLong(ToLongFunction<? super T> getKey)

In all methods, \textit{getKey} refers to a function that obtains the next comparison key.

Finally, \textbf{Comparator} has a method called \textbf{comparing( )}. It returns a comparator that obtains its comparison key from a function passed to the method. There are two versions of \textbf{comparing( )}, shown here:

\begin{verbatim}
static <T, U extends Comparable<? super U>> Comparator<T>
    comparing(Function<? super T, ? extends U> getKey)

static <T, U> Comparator<T>
    comparing(Function<? super T, ? extends U> getKey,
              Comparator<? super U> keyComp)
\end{verbatim}

In both, \textit{getKey} refers to a function that obtains the next comparison key. In the second version, \textit{keyComp} specifies the comparator used to compare keys. \textbf{Comparator} also adds the following specialized versions of these methods for the primitive types:

\begin{verbatim}
static <T> Comparator<T>
    comparingDouble(ToDoubleFunction<? super T> getKey)

static <T> Comparator<T>
    comparingInt(ToIntFunction<? super T> getKey)

static <T> Comparator<T>
    comparingLong(ToLongFunction<? super T> getKey)
\end{verbatim}

In all methods, \textit{getKey} refers to a function that obtains the next comparison key.

\textbf{Using a Comparator}

The following is an example that demonstrates the power of a custom comparator. It implements the \textbf{compare( )} method for strings that operates in reverse of normal. Thus, it causes a tree set to be sorted in reverse order.
As the following output shows, the tree is now sorted in reverse order:

    F E D C B A

Look closely at the **MyComp** class, which implements **Comparator** by implementing **compare()**. (As explained earlier, overriding **equals()** is neither necessary nor common. It is also not necessary to override the default methods.) Inside **compare()**, the **String** method **compareTo()** compares the two strings. However, **bStr**—not **aStr**—invokes **compareTo()**. This causes the outcome of the
comparison to be reversed.

Although the way in which the reverse order comparator is implemented by the preceding program is perfectly adequate, there is another way to approach a solution. It is now possible to simply call `reversed()` on a natural-order comparator. It will return an equivalent comparator, except that it runs in reverse. For example, assuming the preceding program, you can rewrite `MyComp` as a natural-order comparator, as shown here:

```java
class MyComp implements Comparator<String> {
    public int compare(String aStr, String bStr) {
        return aStr.compareTo(bStr);
    }
}
```

Next, you can use the following sequence to create a `TreeSet` that orders its string elements in reverse:

```java
MyComp mc = new MyComp(); // Create a comparator

// Pass a reverse order version of MyComp to TreeSet.
TreeSet<String> ts = new TreeSet<String>(mc.reversed());
```

If you plug this new code into the preceding program, it will produce the same results as before. In this case, there is no advantage gained by using `reversed()`. However, in cases in which you need to create both a natural-order comparator and a reversed comparator, then using `reversed()` gives you an easy way to obtain the reverse-order comparator without having to code it explicitly.

It is not actually necessary to create the `MyComp` class in the preceding examples because a lambda expression can be easily used instead. For example, you can remove the `MyComp` class entirely and create the string comparator by using this statement:

```java
// Use a lambda expression to implement Comparator<String>.
Comparator<String> mc = (aStr, bStr) -> aStr.compareTo(bStr);
```

One other point: in this simple example, it would also be possible to specify a reverse comparator via a lambda expression directly in the call to the `TreeSet()` constructor, as shown here:

```java
// Pass a reversed comparator to TreeSet() via a
// lambda expression.
TreeSet<String> ts = new TreeSet<String>(
    (aStr, bStr) -> bStr.compareTo(aStr));
```
By making these changes, the program is substantially shortened, as its final version shown here illustrates:

```java
// Use a lambda expression to create a reverse comparator.
import java.util.*;

class CompDemo2 {
    public static void main(String args[]) {

        // Pass a reverse comparator to TreeSet() via a
        // lambda expression.
        TreeSet<String> ts = new TreeSet<String>(
            (aStr, bStr) -> bStr.compareTo(aStr));

        // Add elements to the tree set.
        ts.add("C");
        ts.add("A");
        ts.add("B");
        ts.add("E");
        ts.add("F");
        ts.add("D");

        // Display the elements.
        for(String element : ts)
            System.out.print(element + " ");

        System.out.println();
    }
}
```

For a more practical example that uses a custom comparator, the following program is an updated version of the TreeMap program shown earlier that stores account balances. In the previous version, the accounts were sorted by name, but the sorting began with the first name. The following program sorts the accounts by last name. To do so, it uses a comparator that compares the last name of each account. This results in the map being sorted by last name.
// Use a comparator to sort accounts by last name.
import java.util.*;

// Compare last whole words in two strings.
class TComp implements Comparator<String> {
    public int compare(String aStr, String bStr) {
        int i, j, k;

        // Find index of beginning of last name.
        i = aStr.lastIndexOf(' ');
        j = bStr.lastIndexOf(' ');

        k = aStr.substring(i).compareToIgnoreCase(bStr.substring(j));
        if(k==0) // last names match, check entire name
            return aStr.compareToIgnoreCase(bStr);
        else
            return k;
    }
}

// No need to override equals.
}
class TreeMapDemo2 {
    public static void main(String args[]) {
        // Create a tree map.
        TreeMap<String, Double> tm = new TreeMap<String, Double>(new TComp());

        // Put elements to the map.
        tm.put("John Doe", 3434.34);
        tm.put("Tom Smith", 123.22);
        tm.put("Jane Baker", 1378.00);
        tm.put("Tod Hall", 99.22);
        tm.put("Ralph Smith", -19.08);

        // Get a set of the entries.
        Set<Map.Entry<String, Double>> set = tm.entrySet();

        // Display the elements.
        for(Map.Entry<String, Double> me : set) {
            System.out.print(me.getKey() + " : ");
            System.out.println(me.getValue());
        }
        System.out.println();

        // Deposit 1000 into John Doe's account.
        double balance = tm.get("John Doe");
        tm.put("John Doe", balance + 1000);

        System.out.println("John Doe's new balance: " +
                        tm.get("John Doe"));
    }
}
Here is the output; notice that the accounts are now sorted by last name:

   Jane Baker: 1378.0
   John Doe:  3434.34
   Todd Hall:  99.22
   Ralph Smith: -19.08
   Tom Smith:  123.22

   John Doe's new balance: 4434.34

The comparator class TComp compares two strings that hold first and last names. It does so by first comparing last names. To do this, it finds the index of the last space in each string and then compares the substrings of each element that begin at that point. In cases where last names are equivalent, the first names are then compared. This yields a tree map that is sorted by last name, and within last name by first name. You can see this because Ralph Smith comes before Tom Smith in the output.

There is another way that you could code the preceding program so the map is sorted by last name and then by first name. This approach uses the thenComparing() method. Recall that thenComparing() lets you specify a second comparator that will be used if the invoking comparator returns equal. This approach is put into action by the following program, which reworks the preceding example to use thenComparing():

// Use thenComparing() to sort by last, then first name.
import java.util.*;

// A comparator that compares last names.
class CompLastNames implements Comparator<String> {
    public int compare(String aStr, String bStr) {
        int i, j;

        // Find index of beginning of last name.
        i = aStr.lastIndexOf(' ');
        j = bStr.lastIndexOf(' ');

        return aStr.substring(i).compareToIgnoreCase(bStr.substring(j));
    }
}

// Sort by entire name when last names are equal.
class CompThenByFirstName implements Comparator<String> {
    public int compare(String aStr, String bStr) {
        return aStr.compareToIgnoreCase(bStr);
    }
}

class TreeMapDemo2A {
    public static void main(String args[]) {
        // Use thenComparing() to create a comparator that compares
        // last names, then compares entire name when last names match.
        CompLastNames compLN = new CompLastNames();
        Comparator<String> compLastThenFirst =
            compLN.thenComparing(new CompThenByFirstName());

        // Create a tree map.
        TreeMap<String, Double> tm =
            new TreeMap<String, Double>(compLastThenFirst);

        // Put elements to the map.
tm.put("John Doe", 3434.34);
tm.put("Tom Smith", 123.22);
tm.put("Jane Baker", 1378.00);
tm.put("Tod Hall", 99.22);
tm.put("Ralph Smith", -19.08);

        // Get a set of the entries.
        Set<Map.Entry<String, Double>> set = tm.entrySet();

        // Display the elements.
        for (Map.Entry<String, Double> me : set) {
            System.out.print(me.getKey() + " : ");
            System.out.println(me.getValue());
        }
        System.out.println();

        // Deposit 1000 into John Doe's account.
        double balance = tm.get("John Doe");
tm.put("John Doe", balance + 1000);

        System.out.println("John Doe's new balance: " +
            tm.get("John Doe"));
    }
}
This version produces the same output as before. It differs only in how it accomplishes its job. To begin, notice that a comparator called **CompLastNames** is created. This comparator compares only the last names. A second comparator, called **CompThenByFirstName**, compares the entire name, starting with the first name. Next, the **TreeMap** is created by the following sequence:

```java
CompLastNames compLN = new CompLastNames();
Comparator<String> compLastThenFirst =
    compLN.thenComparing(new CompThenByFirstName());
```

Here, the primary comparator is **compLN**. It is an instance of **CompLastNames**. On it is called `thenComparing()`, passing in an instance of **CompThenByFirstName**. The result is assigned to the comparator called **compLastThenFirst**. This comparator is used to construct the **TreeMap**, as shown here:

```java
TreeMap<String, Double> tm =
    new TreeMap<String, Double>(compLastThenFirst);
```

Now, whenever the last names of the items being compared are equal, the entire name, beginning with the first name, is used to order the two. This means that names are ordered based on last name, and within last names, by first names.

One last point: in the interest of clarity, this example explicitly creates two comparator classes called **CompLastNames** and **ThenByFirstName**, but lambda expressions could have been used instead. You might want to try this on your own. Just follow the same general approach described for the **CompDemo2** example shown earlier.

**The Collection Algorithms**

The Collections Framework defines several algorithms that can be applied to collections and maps. These algorithms are defined as static methods within the **Collections** class. They are summarized in Table 19-15.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static &lt;T&gt; boolean addAll(Collection &lt;? super T&gt; c, T... elements)</td>
<td>Inserts the elements specified by elements into the collection specified by c. Returns true if the elements were added and false otherwise.</td>
</tr>
<tr>
<td>static &lt;T&gt; Queue&lt;T&gt; asLifoQueue(Deque&lt;T&gt; c)</td>
<td>Returns a last-in, first-out view of c.</td>
</tr>
<tr>
<td>static &lt;T&gt; int binarySearch(List&lt;? extends T&gt; list, T value, Comparator&lt;? super T&gt; c)</td>
<td>Searches for value in list ordered according to c. Returns the position of value in list, or a negative value if value is not found.</td>
</tr>
<tr>
<td>static &lt;T&gt; int binarySearch(List&lt;? extends Comparable&lt;? super T&gt;&gt; list, T value)</td>
<td>Searches for value in list. The list must be sorted. Returns the position of value in list, or a negative value if value is not found.</td>
</tr>
<tr>
<td>static &lt;E&gt; Collection&lt;E&gt; checkedCollection(Collection&lt;E&gt; c, Class&lt;E&gt; t)</td>
<td>Returns a run-time type-safe view of a collection. An attempt to insert an incompatible element will cause a ClassCastException.</td>
</tr>
<tr>
<td>static &lt;E&gt; List&lt;E&gt; checkedList(List&lt;E&gt; c, Class&lt;E&gt; t)</td>
<td>Returns a run-time type-safe view of a List. An attempt to insert an incompatible element will cause a ClassCastException.</td>
</tr>
<tr>
<td>static &lt;K, V&gt; Map&lt;K, V&gt; checkedMap(Map&lt;K, V&gt; c, Class&lt;K&gt; keyT, Class&lt;V&gt; valueT)</td>
<td>Returns a run-time type-safe view of a Map. An attempt to insert an incompatible element will cause a ClassCastException.</td>
</tr>
<tr>
<td>static &lt;K, V&gt; NavigableMap&lt;K, V&gt; checkedNavigableMap(NavigableMap&lt;K, V&gt; mm, Class&lt;E&gt; keyT, Class&lt;V&gt; valueT)</td>
<td>Returns a run-time type-safe view of a NavigableMap. An attempt to insert an incompatible element will cause a ClassCastException.</td>
</tr>
<tr>
<td>static &lt;E&gt; NavigableSet&lt;E&gt; checkedNavigableSet(NavigableSet&lt;E&gt; ns, Class&lt;E&gt; t)</td>
<td>Returns a run-time type-safe view of a NavigableSet. An attempt to insert an incompatible element will cause a ClassCastException.</td>
</tr>
<tr>
<td>static &lt;E&gt; Queue&lt;E&gt; checkedQueue(Queue&lt;E&gt; q, Class&lt;E&gt; t)</td>
<td>Returns a run-time type-safe view of a Queue. An attempt to insert an incompatible element will cause a ClassCastException.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>static <code>&lt;E&gt;</code> List&lt;<code>E</code>&gt; checkedSet(Set&lt;<code>E</code>&gt; c, Class&lt;<code>E</code>&gt; t)</td>
<td>Returns a run-time type-safe view of a Set. An attempt to insert an incompatible element will cause a ClassCastException.</td>
</tr>
<tr>
<td>static <code>&lt;K, V&gt;</code> SortedMap&lt;<code>K, V&gt;</code> checkedSortedMap(SortedMap&lt;<code>K, V&gt;</code> c, Class&lt;<code>K</code>&gt; keyT, Class&lt;<code>V</code>&gt; valueT)</td>
<td>Returns a run-time type-safe view of a SortedMap. An attempt to insert an incompatible element will cause a ClassCastException.</td>
</tr>
<tr>
<td>static <code>&lt;E&gt;</code> SortedSet&lt;<code>E&gt;</code> checkedSortedSet(SortedSet&lt;<code>E</code>&gt; c, Class&lt;<code>E</code>&gt; t)</td>
<td>Returns a run-time type-safe view of a SortedSet. An attempt to insert an incompatible element will cause a ClassCastException.</td>
</tr>
<tr>
<td>static <code>&lt;T&gt;</code> void copy(List&lt;? super `T&gt;` list1, List&lt;?&gt; extends <code>T&gt;</code> list2)</td>
<td>Copies the elements of list2 to list1.</td>
</tr>
<tr>
<td>static boolean disjoint(Collection&lt;?&gt; `a`, Collection&lt;?&gt; <code>b</code>)</td>
<td>Compares the elements in <code>a</code> to elements in <code>b</code>. Returns true if the two collections contain no common elements (i.e., the collections contain disjoint sets of elements). Otherwise, returns false.</td>
</tr>
<tr>
<td>static <code>&lt;T&gt;</code> Enumeration&lt;<code>T</code>&gt; emptyEnumeration()</td>
<td>Returns an empty enumeration, which is an enumeration with no elements.</td>
</tr>
<tr>
<td>static <code>&lt;T&gt;</code> Iterator&lt;<code>T</code>&gt; emptyIterator()</td>
<td>Returns an empty iterator, which is an iterator with no elements.</td>
</tr>
<tr>
<td>static <code>&lt;T&gt;</code> List&lt;<code>T</code>&gt; emptyList()</td>
<td>Returns an immutable, empty List object of the inferred type.</td>
</tr>
<tr>
<td>static <code>&lt;T&gt;</code> ListIterator&lt;<code>T</code>&gt; emptyListIterator()</td>
<td>Returns an empty list iterator, which is a list iterator that has no elements.</td>
</tr>
<tr>
<td>static <code>&lt;K, V&gt;</code> Map&lt;<code>K, V&gt;</code> emptyMap()</td>
<td>Returns an immutable, empty Map object of the inferred type.</td>
</tr>
<tr>
<td>static <code>&lt;K, V&gt;</code> NavigableMap&lt;<code>K, V&gt;</code> emptyNavigableMap()</td>
<td>Returns an immutable, empty NavigableMap object of the inferred type.</td>
</tr>
<tr>
<td>static <code>&lt;E&gt;</code> NavigableSet&lt;<code>E&gt;</code> emptyNavigableSet()</td>
<td>Returns an immutable, empty NavigableSet object of the inferred type.</td>
</tr>
<tr>
<td>static <code>&lt;T&gt;</code> Set&lt;<code>T</code>&gt; emptySet()</td>
<td>Returns an immutable, empty Set object of the inferred type.</td>
</tr>
<tr>
<td>static <code>&lt;K, V&gt;</code> SortedMap&lt;<code>K, V&gt;</code> emptySortedMap()</td>
<td>Returns an immutable, empty SortedMap object of the inferred type.</td>
</tr>
<tr>
<td>static <code>&lt;E&gt;</code> SortedSet&lt;<code>E</code>&gt; emptySortedSet()</td>
<td>Returns an immutable, empty SortedSet object of the inferred type.</td>
</tr>
<tr>
<td>static <code>&lt;T&gt;</code> Enumeration&lt;<code>T</code>&gt; enumeration(Collection&lt;<code>T</code>&gt; c)</td>
<td>Returns an enumeration over <code>c</code>. (See “The Enumeration Interface,” later in this chapter.)</td>
</tr>
<tr>
<td>static <code>&lt;T&gt;</code> void fill(List&lt;? super <code>T</code>&gt; list, <code>T</code> <code>obj</code>)</td>
<td>Assigns <code>obj</code> to each element of <code>list</code>.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>static int frequency(Collection&lt;?&gt; c, object obj)</td>
<td>Counts the number of occurrences of obj in c and returns the result.</td>
</tr>
<tr>
<td>static int indexOfSubList(List&lt;?&gt; list, List&lt;?&gt; subList)</td>
<td>Searches list for the first occurrence of subList. Returns the index of the first match, or -1 if no match is found.</td>
</tr>
<tr>
<td>static int lastIndexOfSubList(List&lt;?&gt; list, List&lt;?&gt; subList)</td>
<td>Searches list for the last occurrence of subList. Returns the index of the last match, or -1 if no match is found.</td>
</tr>
<tr>
<td>static &lt;T&gt; ArrayList&lt;T&gt; list(Enumeration&lt;T&gt; enum)</td>
<td>Returns an ArrayList that contains the elements of enum.</td>
</tr>
<tr>
<td>static &lt;T&gt; T max(Collection&lt;? extends T&gt; c, Comparator&lt;? super T&gt; comp)</td>
<td>Returns the maximum element in c as determined by comp.</td>
</tr>
<tr>
<td>static &lt;T extends Object &amp; Comparable&lt;? super T&gt;&gt; T max(Collection&lt;? extends T&gt; c)</td>
<td>Returns the maximum element in c as determined by natural ordering. The collection need not be sorted.</td>
</tr>
<tr>
<td>static &lt;T extends Object &amp; Comparable&lt;? super T&gt;&gt; T min(Collection&lt;? extends T&gt; c)</td>
<td>Returns the minimum element in c as determined by comp. The collection need not be sorted.</td>
</tr>
<tr>
<td>static &lt;T extends Object &amp; Comparable&lt;? super T&gt;&gt; T min(Collection&lt;? extends T&gt; c)</td>
<td>Returns the minimum element in c as determined by natural ordering.</td>
</tr>
<tr>
<td>static &lt;T&gt; List&lt;T&gt; nCopies(int num, T obj)</td>
<td>Returns num copies of obj contained in an immutable list. num must be greater than or equal to zero.</td>
</tr>
<tr>
<td>static &lt;E&gt; Set&lt;E&gt; newSetFromMap(Map&lt;E, Boolean&gt; m)</td>
<td>Creates and returns a set backed by the map specified by m, which must be empty at the time this method is called.</td>
</tr>
<tr>
<td>static &lt;T&gt; boolean replaceAll(List&lt;T&gt; list, T old, T new)</td>
<td>Replaces all occurrences of old with new in list. Returns true if at least one replacement occurred. Returns false otherwise.</td>
</tr>
<tr>
<td>static void reverse(List&lt;T&gt; list)</td>
<td>Reverses the sequence in list.</td>
</tr>
<tr>
<td>static &lt;T&gt; Comparator&lt;T&gt; reverseOrder(Comparator&lt;T&gt; comp)</td>
<td>Returns a reverse comparator based on the one passed in comp. That is, the returned comparator reverses the outcome of a comparison that uses comp.</td>
</tr>
<tr>
<td>static &lt;T&gt; Comparator&lt;T&gt; reverseOrder()</td>
<td>Returns a reverse comparator, which is a comparator that reverses the outcome of a comparison between two elements.</td>
</tr>
<tr>
<td>static void rotate(List&lt;T&gt; list, int n)</td>
<td>Rotates list by n places to the right. To rotate left, use a negative value for n.</td>
</tr>
<tr>
<td>static void shuffle(List&lt;T&gt; list, Random r)</td>
<td>Shuffles (i.e., randomizes) the elements in list by using r as a source of random numbers.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>static void shuffle(List&lt;T&gt; list)</td>
<td>Shuffles (i.e., randomizes) the elements in list.</td>
</tr>
<tr>
<td>static &lt;T&gt; Set&lt;T&gt; singleton(T obj)</td>
<td>Returns obj as an immutable set. This is an easy way to convert a single object into a set.</td>
</tr>
<tr>
<td>static &lt;T&gt; List&lt;T&gt; singletonList(T obj)</td>
<td>Returns obj as an immutable list. This is an easy way to convert a single object into a list.</td>
</tr>
<tr>
<td>static &lt;K, V&gt; Map&lt;K, V&gt; singletonMap(K k, V v)</td>
<td>Returns the key/value pair k/v as an immutable map. This is an easy way to convert a single key/value pair into a map.</td>
</tr>
<tr>
<td>static &lt;T&gt; void sort(List&lt;T&gt; list, Comparator&lt;? super T&gt; comp)</td>
<td>Sorts the elements of list as determined by comp.</td>
</tr>
<tr>
<td>static &lt;T extends Comparable&lt;? super T&gt;&gt; void sort(List&lt;T&gt; list)</td>
<td>Sorts the elements of list as determined by their natural ordering.</td>
</tr>
<tr>
<td>static void swap(List&lt;?&gt; list, int idx1, int idx2)</td>
<td>Exchanges the elements in list at the indices specified by idx1 and idx2.</td>
</tr>
<tr>
<td>static &lt;T&gt; Collection&lt;T&gt; synchronizedCollection(Collection&lt;T&gt; c)</td>
<td>Returns a thread-safe collection backed by c.</td>
</tr>
<tr>
<td>static &lt;T&gt; List&lt;T&gt; synchronizedList(List&lt;T&gt; list)</td>
<td>Returns a thread-safe list backed by list.</td>
</tr>
<tr>
<td>static &lt;K, V&gt; Map&lt;K, V&gt; synchronizedMap(Map&lt;K, V&gt; m)</td>
<td>Returns a thread-safe map backed by m.</td>
</tr>
<tr>
<td>static &lt;K, V&gt; NavigableMap&lt;K, V&gt; synchronizedNavigableMap(NavigableMap&lt;K, V&gt; mm)</td>
<td>Returns a synchronized navigable map backed by mm.</td>
</tr>
<tr>
<td>static &lt;T&gt; NavigableSet&lt;T&gt; synchronizedNavigableSet(NavigableSet&lt;T&gt; ns)</td>
<td>Returns a synchronized navigable set backed by ns.</td>
</tr>
<tr>
<td>static &lt;T&gt; Set&lt;T&gt; synchronizedSet(Set&lt;T&gt; s)</td>
<td>Returns a thread-safe set backed by s.</td>
</tr>
<tr>
<td>static &lt;K, V&gt; SortedMap&lt;K, V&gt; synchronizedSortedMap(SortedMap&lt;K, V&gt; sm)</td>
<td>Returns a thread-safe sorted map backed by sm.</td>
</tr>
<tr>
<td>static &lt;T&gt; SortedSet&lt;T&gt; synchronizedSortedSet(SortedSet&lt;T&gt; ss)</td>
<td>Returns a thread-safe sorted set backed by ss.</td>
</tr>
<tr>
<td>static &lt;T&gt; Collection&lt;T&gt; unmodifiableCollection(Collection&lt;? extends T&gt; c)</td>
<td>Returns an unmodifiable collection backed by c.</td>
</tr>
<tr>
<td>static &lt;T&gt; List&lt;T&gt; unmodifiableList(List&lt;? extends T&gt; list)</td>
<td>Returns an unmodifiable list backed by list.</td>
</tr>
<tr>
<td>static &lt;K, V&gt; Map&lt;K, V&gt; unmodifiableMap(Map&lt;? extends K, ? extends V&gt; m)</td>
<td>Returns an unmodifiable map backed by m.</td>
</tr>
</tbody>
</table>
Several of the methods can throw a **ClassCastException**, which occurs when an attempt is made to compare incompatible types, or an **UnsupportedOperationException**, which occurs when an attempt is made to modify an unmodifiable collection. Other exceptions are possible, depending on the method.

One thing to pay special attention to is the set of **checked** methods, such as **checkedCollection()**, which returns what the API documentation refers to as a “dynamically typesafe view” of a collection. This view is a reference to the collection that monitors insertions into the collection for type compatibility at runtime. An attempt to insert an incompatible element will cause a **ClassCastException**. Using such a view is especially helpful during debugging because it ensures that the collection always contains valid elements. Related methods include **checkedSet()**, **checkedList()**, **checkedMap()**, and so on. They obtain a type-safe view for the indicated collection.

Notice that several methods, such as **synchronizedList()** and **synchronizedSet()**, are used to obtain synchronized (thread-safe) copies of the various collections. As a general rule, the standard collections implementations are not synchronized. You must use the synchronization algorithms to provide synchronization. One other point: iterators to synchronized collections must be used within **synchronized** blocks.

The set of methods that begins with **unmodifiable** returns views of the various collections that cannot be modified. These will be useful when you want to grant

---

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>NavigableMap&lt;K, V&gt;</code></td>
<td>Represents an unmodifiable navigable map backed by <code>nm</code>.</td>
</tr>
<tr>
<td><code>NavigableSet&lt;T&gt;</code></td>
<td>Represents an unmodifiable navigable set backed by <code>ns</code>.</td>
</tr>
<tr>
<td><code>Set&lt;T&gt;</code></td>
<td>Represents an unmodifiable set backed by <code>s</code>.</td>
</tr>
<tr>
<td><code>SortedMap&lt;K, V&gt;</code></td>
<td>Represents an unmodifiable sorted map backed by <code>sm</code>.</td>
</tr>
<tr>
<td><code>SortedSet&lt;T&gt;</code></td>
<td>Represents an unmodifiable sorted set backed by <code>ss</code>.</td>
</tr>
</tbody>
</table>

---

Table 19-15  The Algorithms Defined by **Collections**
some process read—but not write—capabilities on a collection.

Collections defines three static variables: EMPTY_SET, EMPTY_LIST, and EMPTY_MAP. All are immutable.

The following program demonstrates some of the algorithms. It creates and initializes a linked list. The reverseOrder( ) method returns a Comparator that reverses the comparison of Integer objects. The list elements are sorted according to this comparator and then are displayed. Next, the list is randomized by calling shuffle( ), and then its minimum and maximum values are displayed.
// Demonstrate various algorithms.
import java.util.*;

class AlgorithmsDemo {
    public static void main(String args[]) {

        // Create and initialize linked list.
        LinkedList<Integer> ll = new LinkedList<Integer>();
        ll.add(-8);
        ll.add(20);
        ll.add(-20);
        ll.add(8);

        // Create a reverse order comparator.
        Comparator<Integer> r = Collections.reverseOrder();

        // Sort list by using the comparator.
        Collections.sort(ll, r);

        System.out.print("List sorted in reverse: ");
        for(int i : ll)
            System.out.print(i + " ");

        System.out.println();

        // Shuffle list.
        Collections.shuffle(ll);

        // Display randomized list.
        System.out.print("List shuffled: ");
        for(int i : ll)
            System.out.print(i + " ");

        System.out.println();
        System.out.println("Minimum: "+ Collections.min(ll));
        System.out.println("Maximum: "+ Collections.max(ll));
    }
}

Output from this program is shown here:

List sorted in reverse: 20 8 -8 -20
List shuffled: 20 -20 8 -8
Minimum: -20
Maximum: 20
Notice that \texttt{min()} and \texttt{max()} operate on the list after it has been shuffled. Neither requires a sorted list for its operation.

\section*{Arrays}

The \texttt{Arrays} class provides various methods that are useful when working with arrays. These methods help bridge the gap between collections and arrays. Each method defined by \texttt{Arrays} is examined in this section.

The \texttt{asList()} method returns a \texttt{List} that is backed by a specified array. In other words, both the list and the array refer to the same location. It has the following signature:

\begin{verbatim}
static <T> List asList(T… array)
\end{verbatim}

Here, \texttt{array} is the array that contains the data.

The \texttt{binarySearch()} method uses a binary search to find a specified value. This method must be applied to sorted arrays. Here are some of its forms. (Additional forms let you search a subrange):

\begin{verbatim}
static int binarySearch(byte array[], byte value)
static int binarySearch(char array[], char value)
static int binarySearch(double array[], double value)
static int binarySearch(float array[], float value)
static int binarySearch(int array[], int value)
static int binarySearch(long array[], long value)
static int binarySearch(short array[], short value)
static int binarySearch(Object array[], Object value)
static <T> int binarySearch(T[] array, T value, Comparator<? super T> c)
\end{verbatim}

Here, \texttt{array} is the array to be searched, and \texttt{value} is the value to be located. The last two forms throw a \texttt{ClassCastException} if \texttt{array} contains elements that cannot be compared (for example, \texttt{Double} and \texttt{StringBuffer}) or if \texttt{value} is not compatible with the types in \texttt{array}. In the last form, the \texttt{Comparator} \texttt{c} is used to determine the order of the elements in \texttt{array}. In all cases, if \texttt{value} exists in \texttt{array}, the index of the element is returned. Otherwise, a negative value is returned.

The \texttt{copyOf()} method returns a copy of an array and has the following forms:

\begin{verbatim}
static boolean[] copyOf(boolean[] source, int len)
static byte[] copyOf(byte[] source, int len)
static char[] copyOf(char[] source, int len)
\end{verbatim}
static double[ ] copyOf(double[ ] source, int len)
static float[ ] copyOf(float[ ] source, int len)
static int[ ] copyOf(int[ ] source, int len)
static long[ ] copyOf(long[ ] source, int len)
static short[ ] copyOf(short[ ] source, int len)
static <T> T[ ] copyOf(T[ ] source, int len)
static <T,U> T[ ] copyOf(U[ ] source, int len, Class<? extends T[ ]> resultT)

The original array is specified by source, and the length of the copy is specified by len. If the copy is longer than source, then the copy is padded with zeros (for numeric arrays), nulls (for object arrays), or false (for boolean arrays). If the copy is shorter than source, then the copy is truncated. In the last form, the type of resultT becomes the type of the array returned. If len is negative, a NegativeArraySizeException is thrown. If source is null, a NullPointerException is thrown. If resultT is incompatible with the type of source, an ArrayStoreException is thrown.

The copyOfRange( ) method returns a copy of a range within an array and has the following forms:

static boolean[ ] copyOfRange(boolean[ ] source, int start, int end)
static byte[ ] copyOfRange(byte[ ] source, int start, int end)
static char[ ] copyOfRange(char[ ] source, int start, int end)
static double[ ] copyOfRange(double[ ] source, int start, int end)
static float[ ] copyOfRange(float[ ] source, int start, int end)
static int[ ] copyOfRange(int[ ] source, int start, int end)
static long[ ] copyOfRange(long[ ] source, int start, int end)
static short[ ] copyOfRange(short[ ] source, int start, int end)
static <T> T[ ] copyOfRange(T[ ] source, int start, int end)
static <T,U> T[ ] copyOfRange(U[ ] source, int start, int end, Class<? extends T[ ]> resultT)

The original array is specified by source. The range to copy is specified by the indices passed via start and end. The range runs from start to end – 1. If the range is longer than source, then the copy is padded with zeros (for numeric arrays), nulls (for object arrays), or false (for boolean arrays). In the last form, the type of resultT becomes the type of the array returned. If start is negative or greater than the length of source, an ArrayIndexOutOfBoundsException is thrown. If start is greater than
end, an **IllegalArgumentException** is thrown. If `source` is **null**, a
**NullPointerException** is thrown. If `resultT` is incompatible with the type of `source`, an **ArrayStoreException** is thrown.

The `equals( )` method returns **true** if two arrays are equivalent. Otherwise, it returns **false**. Here are a number of its forms. Several more versions have been added by JDK 9 that let you specify a range and/or a comparator.

```java
static boolean equals(boolean array1[ ], boolean array2 [ ])
static boolean equals(byte array1[ ], byte array2 [ ])
static boolean equals(char array1[ ], char array2 [ ])
static boolean equals(double array1[ ], double array2 [ ])
static boolean equals(float array1[ ], float array2 [ ])
static boolean equals(int array1[ ], int array2 [ ])
static boolean equals(long array1[ ], long array2 [ ])
static boolean equals(short array1[ ], short array2 [ ])
static boolean equals(Object array1[ ], Object array2 [ ])
```

Here, `array1` and `array2` are the two arrays that are compared for equality.

The **deepEquals( )** method can be used to determine if two arrays, which might contain nested arrays, are equal. It has this declaration:

```java
static boolean deepEquals(Object[ ] a, Object[ ] b)
```

It returns **true** if the arrays passed in `a` and `b` contain the same elements. If `a` and `b` contain nested arrays, then the contents of those nested arrays are also checked. It returns **false** if the arrays, or any nested arrays, differ.

The **fill( )** method assigns a value to all elements in an array. In other words, it fills an array with a specified value. The **fill( )** method has two versions. The first version, which has the following forms, fills an entire array:

```java
static void fill(boolean array[ ], boolean value)
static void fill(byte array[ ], byte value)
static void fill(char array[ ], char value)
static void fill(double array[ ], double value)
static void fill(float array[ ], float value)
static void fill(int array[ ], int value)
static void fill(long array[ ], long value)
```
static void fill(short array[ ], short value)
static void fill(Object array[ ], Object value)

Here, value is assigned to all elements in array. The second version of the fill( ) method assigns a value to a subset of an array.

The sort( ) method sorts an array so that it is arranged in ascending order. The sort( ) method has two versions. The first version, shown here, sorts the entire array:

   static void sort(byte array[ ])
   static void sort(char array[ ])
   static void sort(double array[ ])
   static void sort(float array[ ])
   static void sort(int array[ ])
   static void sort(long array[ ])
   static void sort(short array[ ])
   static void sort(Object array[ ])
   static <T> void sort(T array[ ], Comparator<? super T> c)

Here, array is the array to be sorted. In the last form, c is a Comparator that is used to order the elements of array. The last two forms can throw a ClassCastException if elements of the array being sorted are not comparable. The second version of sort( ) enables you to specify a range within an array that you want to sort.

One quite powerful method in Arrays is parallelSort( ) because it sorts, into ascending order, portions of an array in parallel and then merges the results. This approach can greatly speed up sorting times. Like sort( ), there are two basic types of parallelSort( ), each with several overloads. The first type sorts the entire array. It is shown here:

   static void parallelSort(byte array[ ])
   static void parallelSort(char array[ ])
   static void parallelSort(double array[ ])
   static void parallelSort(float array[ ])
   static void parallelSort(int array[ ])
   static void parallelSort(long array[ ])
   static void parallelSort(short array[ ])
   static <T extends Comparable<? super T>> void parallelSort(T array[ ])
   static <T> void parallelSort(T array[ ], Comparator<? super T> c)
Here, array is the array to be sorted. In the last form, c is a comparator that is used to order the elements in the array. The last two forms can throw a \texttt{ClassCastException} if the elements of the array being sorted are not comparable. The second version of \texttt{parallelSort( )} enables you to specify a range within the array that you want to sort.

Arrays supports spliterators by including the \texttt{spliterator( )} method. It has two basic forms. The first type returns a spliterator to an entire array. It is shown here:

- \texttt{static Spliterator.OfDouble spliterator(double array[])}
- \texttt{static Spliterator.OfInt spliterator(int array[])}
- \texttt{static Spliterator.OfLong spliterator(long array[])}
- \texttt{static \langle T\rangle Spliterator spliterator(T array[])}

Here, array is the array that the spliterator will cycle through. The second version of \texttt{spliterator( )} enables you to specify a range to iterate within the array.

Arrays supports the \texttt{Stream} interface by including the \texttt{stream( )} method. It has two forms. The first is shown here:

- \texttt{static DoubleStream stream(double array[])}
- \texttt{static IntStream stream(int array[])}
- \texttt{static LongStream stream(long array[])}
- \texttt{static \langle T\rangle Stream stream(T array[])}

Here, array is the array to which the stream will refer. The second version of \texttt{stream( )} enables you to specify a range within the array.

Another two methods are related: \texttt{setAll( )} and \texttt{parallelSetAll( )}. Both assign values to all of the elements, but \texttt{parallelSetAll( )} works in parallel. Here is an example of each:

- \texttt{static void setAll(double array[],
                          IntToDoubleFunction<? extends T> genVal)}
- \texttt{static void parallelSetAll(double array[],
                                   IntToDoubleFunction<? extends T> genVal)}

Several overloads exist for each of these that handle types \texttt{int}, \texttt{long}, and generic.

One of the more intriguing methods defined by Arrays is called \texttt{parallelPrefix( )}, and it modifies an array so that each element contains the cumulative result of an operation applied to all previous elements. For example, if the operation is multiplication, then on return, the array elements will contain the values associated with the running product of the original values. It has several overloads. Here is one
static void parallelPrefix(double array[ ], DoubleBinaryOperator func)

Here, array is the array being acted upon, and func specifies the operation applied. (DoubleBinaryOperator is a functional interface defined in java.util.function.) Many other versions are provided, including those that operate on types int, long, and generic, and those that let you specify a range within the array on which to operate.

JDK 9 adds three comparison methods to Arrays. They are compare(), compareUnsigned(), and mismatch(). Each has several overloads and each has versions that let you define a range to compare. Here is a brief description of each. The compare() method compares two arrays. It returns zero if they are the same, a positive value if the first array is greater than the second, and negative if the first array is less than the second. To perform an unsigned comparison of two arrays that hold integer values, use compareUnsigned(). To find the location of the first mismatch between two arrays, use mismatch(). It returns the index of the mismatch, or -1 if the arrays are equivalent.

Arrays also provides toString() and hashCode() for the various types of arrays. In addition, deepToString() and deepHashCode() are provided, which operate effectively on arrays that contain nested arrays.

The following program illustrates how to use some of the methods of the Arrays class:
// Demonstrate Arrays
import java.util.*;

class ArraysDemo {
    public static void main(String args[]) {

        // Allocate and initialize array.
        int array[] = new int[10];
        for(int i = 0; i < 10; i++)
            array[i] = -3 * i;

        // Display, sort, and display the array.
        System.out.print("Original contents: ");
        display(array);
        Arrays.sort(array);
        System.out.print("Sorted: ");
        display(array);

        // Fill and display the array.
        Arrays.fill(array, 2, 6, -1);
        System.out.print("After fill(): ");
        display(array);

        // Sort and display the array.
        Arrays.sort(array);
        System.out.print("After sorting again: ");
        display(array);

        // Binary search for -9.
        System.out.print("The value -9 is at location ");
        int index =
            Arrays.binarySearch(array, -9);

        System.out.println(index);
    }
}

static void display(int array[]) {
    for(int i: array)
        System.out.print(i + " ");
    System.out.println();
}
The following is the output from this program:

```
Original contents: 0 -3 -6 -9 -12 -15 -18 -21 -24 -27
Sorted: -27 -24 -21 -18 -15 -12 -9 -6 -3 0
After fill(): -27 -24 -1 -1 -1 -9 -6 -3 0
After sorting again: -27 -24 -9 -6 -3 -1 -1 -1 -1 0
The value -9 is at location 2
```

## The Legacy Classes and Interfaces

As explained at the start of this chapter, early versions of `java.util` did not include the Collections Framework. Instead, it defined several classes and an interface that provided an ad hoc method of storing objects. When collections were added (by J2SE 1.2), several of the original classes were reengineered to support the collection interfaces. Thus, they are now technically part of the Collections Framework. However, where a modern collection duplicates the functionality of a legacy class, you will usually want to use the newer collection class.

One other point: none of the modern collection classes described in this chapter are synchronized, but all the legacy classes are synchronized. This distinction may be important in some situations. Of course, you can easily synchronize collections by using one of the algorithms provided by `Collections`.

The legacy classes defined by `java.util` are shown here:

<table>
<thead>
<tr>
<th>Dictionary</th>
<th>Hashtable</th>
<th>Properties</th>
<th>Stack</th>
<th>Vector</th>
</tr>
</thead>
</table>

There is one legacy interface called `Enumeration`. The following sections examine `Enumeration` and each of the legacy classes, in turn.

## The Enumeration Interface

The `Enumeration` interface defines the methods by which you can enumerate (obtain one at a time) the elements in a collection of objects. This legacy interface has been superseded by `Iterator`. Although not deprecated, `Enumeration` is considered obsolete for new code. However, it is used by several methods defined by the legacy classes (such as `Vector` and `Properties`) and is used by several other API classes. Because it is still in use, it was retrofitted for generics by JDK 5. It has this declaration:

```java
interface Enumeration<E>
```

where `E` specifies the type of element being enumerated.
**Enumeration** specifies the following two abstract methods:

```java
boolean hasMoreElements( )
E nextElement( )
```

When implemented, `hasMoreElements( )` must return `true` while there are still more elements to extract, and `false` when all the elements have been enumerated. `nextElement( )` returns the next object in the enumeration. That is, each call to `nextElement( )` obtains the next object in the enumeration. It throws `NoSuchElementException` when the enumeration is complete.

JDK 9 adds a default method to `Enumeration` called `asIterator( )`. It is shown here:

```java
default Iterator<E> asIterator( )
```

It returns an iterator to the elements in the enumeration. As such, it provides an easy way to convert an old-style `Enumeration` into a modern `Iterator`. Furthermore, if a portion of the elements in the enumeration have already been read prior to calling `asIterator( )`, the returned iterator accesses only the remaining elements.

**Vector**

`Vector` implements a dynamic array. It is similar to `ArrayList`, but with two differences: `Vector` is synchronized, and it contains many legacy methods that duplicate the functionality of methods defined by the Collections Framework. With the advent of collections, `Vector` was reengineered to extend `AbstractList` and to implement the `List` interface. With the release of JDK 5, it was retrofitted for generics and reengineered to implement `Iterable`. This means that `Vector` is fully compatible with collections, and a `Vector` can have its contents iterated by the enhanced for loop.

`Vector` is declared like this:

```java
class Vector<E>
```

Here, `E` specifies the type of element that will be stored.

Here are the `Vector` constructors:

```java
Vector( )
Vector(int size)
Vector(int size, int incr)
```
Vector(Collection<? extends E> c)

The first form creates a default vector, which has an initial size of 10. The second form creates a vector whose initial capacity is specified by size. The third form creates a vector whose initial capacity is specified by size and whose increment is specified by incr. The increment specifies the number of elements to allocate each time that a vector is resized upward. The fourth form creates a vector that contains the elements of collection c.

All vectors start with an initial capacity. After this initial capacity is reached, the next time that you attempt to store an object in the vector, the vector automatically allocates space for that object plus extra room for additional objects. By allocating more than just the required memory, the vector reduces the number of allocations that must take place as the vector grows. This reduction is important, because allocations are costly in terms of time. The amount of extra space allocated during each reallocation is determined by the increment that you specify when you create the vector. If you don’t specify an increment, the vector’s size is doubled by each allocation cycle.

Vector defines these protected data members:

```java
int capacityIncrement;
int elementCount;
Object[] elementData;
```

The increment value is stored in capacityIncrement. The number of elements currently in the vector is stored in elementCount. The array that holds the vector is stored in elementData.

In addition to the collections methods specified by List, Vector defines several legacy methods, which are summarized in Table 19-16.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void addElement(E element)</td>
<td>The object specified by element is added to the vector.</td>
</tr>
<tr>
<td>int capacity()</td>
<td>Returns the capacity of the vector.</td>
</tr>
<tr>
<td>Object clone()</td>
<td>Returns a duplicate of the invoking vector.</td>
</tr>
<tr>
<td>boolean contains(Object element)</td>
<td>Returns true if element is contained by the vector, and returns false if it is not.</td>
</tr>
<tr>
<td>void copyInto(Object array[])</td>
<td>The elements contained in the invoking vector are copied into the array specified by array.</td>
</tr>
<tr>
<td>E elementAt(int index)</td>
<td>Returns the element at the location specified by index.</td>
</tr>
<tr>
<td>Enumeration&lt;E&gt; elements()</td>
<td>Returns an enumeration of the elements in the vector.</td>
</tr>
<tr>
<td>void ensureCapacity(int size)</td>
<td>Sets the minimum capacity of the vector to size.</td>
</tr>
<tr>
<td>E firstElement()</td>
<td>Returns the first element in the vector.</td>
</tr>
<tr>
<td>int indexOf(Object element)</td>
<td>Returns the index of the first occurrence of element. If the object is not in the vector, -1 is returned.</td>
</tr>
<tr>
<td>int indexOf(Object element, int start)</td>
<td>Returns the index of the first occurrence of element at or after start. If the object is not in that portion of the vector, -1 is returned.</td>
</tr>
</tbody>
</table>
Because `Vector` implements `List`, you can use a vector just like you use an `ArrayList` instance. You can also manipulate one using its legacy methods. For example, after you instantiate a `Vector`, you can add an element to it by calling `addElement( )`. To obtain the element at a specific location, call `elementAt( )`. To obtain the first element in the vector, call `firstElement( )`. To retrieve the last element, call `lastElement( )`. You can obtain the index of an element by using

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void insertElementAt(E element, int index)</code></td>
<td>Adds <code>element</code> to the vector at the location specified by <code>index</code>.</td>
</tr>
<tr>
<td><code>boolean isEmpty()</code></td>
<td>Returns <code>true</code> if the vector is empty, and returns <code>false</code> if it contains one or more elements.</td>
</tr>
<tr>
<td><code>E lastElement()</code></td>
<td>Returns the last element in the vector.</td>
</tr>
<tr>
<td><code>int lastIndexOf(Object element)</code></td>
<td>Returns the index of the last occurrence of <code>element</code>. If the object is not in the vector, –1 is returned.</td>
</tr>
<tr>
<td><code>int lastIndexOf(Object element, int start)</code></td>
<td>Returns the index of the last occurrence of <code>element</code> before <code>start</code>. If the object is not in that portion of the vector, –1 is returned.</td>
</tr>
<tr>
<td><code>void removeAllElements()</code></td>
<td>Empties the vector. After this method executes, the size of the vector is zero.</td>
</tr>
<tr>
<td><code>boolean removeElement(Object element)</code></td>
<td>Removes <code>element</code> from the vector. If more than one instance of the specified object exists in the vector, then it is the first one that is removed. Returns <code>true</code> if successful and <code>false</code> if the object is not found.</td>
</tr>
<tr>
<td><code>void removeElementAt(int index)</code></td>
<td>Removes the element at the location specified by <code>index</code>.</td>
</tr>
<tr>
<td><code>void setElementAt(E element, int index)</code></td>
<td>The location specified by <code>index</code> is assigned <code>element</code>.</td>
</tr>
<tr>
<td><code>void setSize(int size)</code></td>
<td>Sets the number of elements in the vector to <code>size</code>. If the new size is less than the old size, elements are lost. If the new size is larger than the old size, <code>null</code> elements are added.</td>
</tr>
<tr>
<td><code>int size()</code></td>
<td>Returns the number of elements currently in the vector.</td>
</tr>
<tr>
<td><code>String toString()</code></td>
<td>Returns the string equivalent of the vector.</td>
</tr>
<tr>
<td><code>void trimToSize()</code></td>
<td>Sets the vector’s capacity equal to the number of elements that it currently holds.</td>
</tr>
</tbody>
</table>

Table 19-16  The Legacy Methods Defined by Vector
indexOf( ) and lastIndexOf( ). To remove an element, call `removeElement( )` or `removeElementAt( )`.

The following program uses a vector to store various types of numeric objects. It demonstrates several of the legacy methods defined by `Vector`. It also demonstrates the `Enumeration` interface.
// Demonstrate various Vector operations.
import java.util.*;

class VectorDemo {
    public static void main(String args[]) {

        // initial size is 3, increment is 2
        Vector<Integer> v = new Vector<Integer>(3, 2);

        System.out.println("Initial size: " + v.size());
        System.out.println("Initial capacity: " +
                        v.capacity());

        v.addElement(1);
        v.addElement(2);
        v.addElement(3);
        v.addElement(4);

        System.out.println("Capacity after four additions: " +
                        v.capacity());

        v.addElement(5);
        System.out.println("Current capacity: " +
                        v.capacity());

        v.addElement(6);
        v.addElement(7);

        System.out.println("Current capacity: " +
                        v.capacity());

        v.addElement(9);
        v.addElement(10);

        System.out.println("Current capacity: " +
                        v.capacity());

        v.addElement(11);
        v.addElement(12);

        System.out.println("First element: " + v.firstElement());
        System.out.println("Last element: " + v.lastElement());

        if(v.contains(3))
            System.out.println("Vector contains 3.");

        // Enumerate the elements in the vector.
        Enumeration<Integer> vEnum = v.elements();

        System.out.println("\nElements in vector:");
        while(vEnum.hasMoreElements())
            System.out.print(vEnum.nextElement() + " ");
        System.out.println();
    }
}
The output from this program is shown here:

```
Initial size: 0
Initial capacity: 3
Capacity after four addi
Current capacity: 5
Current capacity: 7
Current capacity: 9
First element: 1
Last element: 12
Vector contains 3.
```

```
Elements in vector:
1 2 3 4 5 6 7 9 10 11 12
```

Instead of relying on an enumeration to cycle through the objects (as the preceding program does), you can use an iterator. For example, the following iterator-based code can be substituted into the program:

```
// Use an iterator to display contents.
Iterator<Integer> vItr = v.iterator();
System.out.println("\nElements in vector:");
while (vItr.hasNext())
    System.out.print(vItr.next() + " ");
System.out.println();
```

You can also use a for-each for loop to cycle through a Vector, as the following version of the preceding code shows:

```
// Use an enhanced for loop to display contents
System.out.println("\nElements in vector:");
for (int i : v)
    System.out.print(i + " ");
System.out.println();
```

Because the Enumeration interface is not recommended for new code, you will usually use an iterator or a for-each for loop to enumerate the contents of a vector. Of course, legacy code will employ Enumeration. Fortunately, enumerations and iterators work in nearly the same manner.

**Stack**
**Stack** is a subclass of **Vector** that implements a standard last-in, first-out stack. **Stack** only defines the default constructor, which creates an empty stack. With the release of JDK 5, **Stack** was retrofitted for generics and is declared as shown here:

```
class Stack<E>
```

Here, **E** specifies the type of element stored in the stack.

**Stack** includes all the methods defined by **Vector** and adds several of its own, shown in **Table 19-17**.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean empty( )</td>
<td>Returns <strong>true</strong> if the stack is empty, and returns <strong>false</strong> if the stack contains elements.</td>
</tr>
<tr>
<td>E peek( )</td>
<td>Returns the element on the top of the stack, but does not remove it.</td>
</tr>
<tr>
<td>E pop( )</td>
<td>Returns the element on the top of the stack, removing it in the process.</td>
</tr>
<tr>
<td>E push(E element)</td>
<td>Pushes <strong>element</strong> onto the stack. <strong>element</strong> is also returned.</td>
</tr>
<tr>
<td>int search(Object element)</td>
<td>Searches for <strong>element</strong> in the stack. If found, its offset from the top of the stack is returned. Otherwise, –1 is returned.</td>
</tr>
</tbody>
</table>

**Table 19-17**  The Methods Defined by **Stack**

To put an object on the top of the stack, call **push( )**. To remove and return the top element, call **pop( )**. You can use **peek( )** to return, but not remove, the top object. An **EmptyStackException** is thrown if you call **pop( )** or **peek( )** when the invoking stack is empty. The **empty( )** method returns **true** if nothing is on the stack. The **search( )** method determines whether an object exists on the stack and returns the number of pops that are required to bring it to the top of the stack. Here is an example that creates a stack, pushes several **Integer** objects onto it, and then pops them off again:
// Demonstrate the Stack class.
import java.util.*;

class StackDemo {
    static void showpush(Stack<Integer> st, int a) {
        st.push(a);
        System.out.println("push( " + a + ")");
        System.out.println("stack: " + st);
    }

    static void showpop(Stack<Integer> st) {
        System.out.print("pop -> ");
        Integer a = st.pop();
        System.out.println(a);
        System.out.println("stack: " + st);
    }

    public static void main(String args[]) {
        Stack<Integer> st = new Stack<Integer>();
        System.out.println("stack: " + st);
        showpush(st, 42);
        showpush(st, 66);
        showpush(st, 99);
        showpop(st);
        showpop(st);
        showpop(st);

        try {
            showpop(st);
        } catch (EmptyStackException e) {
            System.out.println("empty stack");
        }
    }
}

The following is the output produced by the program; notice how the exception handler for EmptyStackException is used so that you can gracefully handle a stack underflow:
One other point: although Stack is not deprecated, ArrayDeque is a better choice.

**Dictionary**

Dictionary is an abstract class that represents a key/value storage repository and operates much like Map. Given a key and value, you can store the value in a Dictionary object. Once the value is stored, you can retrieve it by using its key. Thus, like a map, a dictionary can be thought of as a list of key/value pairs. Although not currently deprecated, Dictionary is classified as obsolete, because it is fully superseded by Map. However, Dictionary is still in use and thus is discussed here.

With the advent of JDK 5, Dictionary was made generic. It is declared as shown here:

```java
class Dictionary<K, V>
```

Here, K specifies the type of keys, and V specifies the type of values. The abstract methods defined by Dictionary are listed in Table 19-18.
Table 19-18  The Abstract Methods Defined by Dictionary

<table>
<thead>
<tr>
<th>Method</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enumeration(&lt;V&gt;) elements()</td>
<td>Returns an enumeration of the values contained in the dictionary.</td>
</tr>
<tr>
<td>V get(Object key)</td>
<td>Returns the object that contains the value associated with key. If key is not in the dictionary, a null object is returned.</td>
</tr>
<tr>
<td>boolean isEmpty()</td>
<td>Returns true if the dictionary is empty, and returns false if it contains at least one key.</td>
</tr>
<tr>
<td>Enumeration(&lt;K&gt;) keys()</td>
<td>Returns an enumeration of the keys contained in the dictionary.</td>
</tr>
<tr>
<td>V put(K key, V value)</td>
<td>Inserts a key and its value into the dictionary. Returns null if key is not already in the dictionary; returns the previous value associated with key if key is already in the dictionary.</td>
</tr>
<tr>
<td>V remove(Object key)</td>
<td>Removes key and its value. Returns the value associated with key. If key is not in the dictionary, a null is returned.</td>
</tr>
<tr>
<td>int size()</td>
<td>Returns the number of entries in the dictionary.</td>
</tr>
</tbody>
</table>

To add a key and a value, use the put() method. Use get() to retrieve the value of a given key. The keys and values can each be returned as an Enumeration by the keys() and elements() methods, respectively. The size() method returns the number of key/value pairs stored in a dictionary, and isEmpty() returns true when the dictionary is empty. You can use the remove() method to delete a key/value pair.

REMEMBER The Dictionary class is obsolete. You should implement the Map interface to obtain key/value storage functionality.

Hashtable

Hashtable was part of the original java.util and is a concrete implementation of a Dictionary. However, with the advent of collections, Hashtable was reengineered to also implement the Map interface. Thus, Hashtable is integrated into the Collections Framework. It is similar to HashMap, but is synchronized.

Like HashMap, Hashtable stores key/value pairs in a hash table. However, neither keys nor values can be null. When using a Hashtable, you specify an object that is used as a key, and the value that you want linked to that key. The key is then hashed, and the resulting hash code is used as the index at which the value is stored within the table.

Hashtable was made generic by JDK 5. It is declared like this:
class Hashtable<K, V>

Here, K specifies the type of keys, and V specifies the type of values.

A hash table can only store keys that override the `hashCode()` and `equals()` methods that are defined by `Object`. The `hashCode()` method must compute and return the hash code for the object. Of course, `equals()` compares two objects. Fortunately, many of Java’s built-in classes already implement the `hashCode()` method. For example, the most common type of `Hashtable` uses a `String` object as the key. `String` implements both `hashCode()` and `equals()`.

The `Hashtable` constructors are shown here:

```
Hashtable( )
Hashtable(int size)
Hashtable(int size, float fillRatio)
Hashtable(Map<? extends K, ? extends V> m)
```

The first version is the default constructor. The second version creates a hash table that has an initial size specified by `size`. (The default size is 11.) The third version creates a hash table that has an initial size specified by `size` and a fill ratio specified by `fillRatio`. This ratio (also referred to as a load factor) must be between 0.0 and 1.0, and it determines how full the hash table can be before it is resized upward. Specifically, when the number of elements is greater than the capacity of the hash table multiplied by its fill ratio, the hash table is expanded. If you do not specify a fill ratio, then 0.75 is used. Finally, the fourth version creates a hash table that is initialized with the elements in `m`. The default load factor of 0.75 is used.

In addition to the methods defined by the `Map` interface, which `Hashtable` now implements, `Hashtable` defines the legacy methods listed in Table 19-19. Several methods throw `NullPointerException` if an attempt is made to use a null key or value.
Table 19-19  The Legacy Methods Defined by Hashtable

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void clear()</td>
<td>Resets and empties the hash table.</td>
</tr>
<tr>
<td>Object clone()</td>
<td>Returns a duplicate of the invoking object.</td>
</tr>
<tr>
<td>boolean contains(Object value)</td>
<td>Returns true if some value equal to value exists within the hash table.</td>
</tr>
<tr>
<td></td>
<td>Returns false if the value isn't found.</td>
</tr>
<tr>
<td>boolean containsKey(Object key)</td>
<td>Returns true if some key equal to key exists within the hash table.</td>
</tr>
<tr>
<td></td>
<td>Returns false if the key isn't found.</td>
</tr>
<tr>
<td>boolean containsValue(Object value)</td>
<td>Returns true if some value equal to value exists within the hash table.</td>
</tr>
<tr>
<td></td>
<td>Returns false if the value isn't found.</td>
</tr>
<tr>
<td>Enumeration&lt;V&gt; elements()</td>
<td>Returns an enumeration of the values contained in the hash table.</td>
</tr>
<tr>
<td>V get(Object key)</td>
<td>Returns the object that contains the value associated with key.</td>
</tr>
<tr>
<td></td>
<td>If key is not in the hash table, a null object is returned.</td>
</tr>
<tr>
<td>boolean isEmpty()</td>
<td>Returns true if the hash table is empty; returns false if it contains at least one key.</td>
</tr>
<tr>
<td>Enumeration&lt;K&gt; keys()</td>
<td>Returns an enumeration of the keys contained in the hash table.</td>
</tr>
<tr>
<td>V put(K key, V value)</td>
<td>Inserts a key and a value into the hash table. Returns null if key isn't already in the hash table; returns the previous value associated with key if key is already in the hash table.</td>
</tr>
<tr>
<td>void rehash()</td>
<td>Increases the size of the hash table and rehashes all of its keys.</td>
</tr>
<tr>
<td>V remove(Object key)</td>
<td>Removes key and its value. Returns the value associated with key.</td>
</tr>
<tr>
<td></td>
<td>If key is not in the hash table, a null object is returned.</td>
</tr>
<tr>
<td>int size()</td>
<td>Returns the number of entries in the hash table.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Returns the string equivalent of a hash table.</td>
</tr>
</tbody>
</table>

The following example reworks the bank account program, shown earlier, so that it uses a Hashtable to store the names of bank depositors and their current balances:
// Demonstrate a Hashtable.
import java.util.*;

class HTDemo {
    public static void main(String args[]) {
        Hashtable<String, Double> balance =
            new Hashtable<String, Double>();

        Enumeration<String> names;
        String str;
        double bal;

        balance.put("John Doe", 3434.34);
        balance.put("Tom Smith", 123.22);
        balance.put("Jane Baker", 1378.00);
        balance.put("Tod Hall", 99.22);
        balance.put("Ralph Smith", -19.08);

        // Show all balances in hashtable.
        names = balance.keys();
        while(names.hasMoreElements()) {
            str = names.nextElement();
            System.out.println(str + " : " +
                balance.get(str));
        }

        System.out.println();

        // Deposit 1,000 into John Doe's account.
        bal = balance.get("John Doe");
        balance.put("John Doe", bal+1000);
        System.out.println("John Doe's new balance: " +
            balance.get("John Doe"));
    }
}

The output from this program is shown here:
One important point: Like the map classes, **Hashtable** does not directly support iterators. Thus, the preceding program uses an enumeration to display the contents of **balance**. However, you can obtain set-views of the hash table, which permits the use of iterators. To do so, you simply use one of the collection-view methods defined by **Map**, such as **entrySet()** or **keySet()**. For example, you can obtain a set-view of the keys and cycle through them using either an iterator or an enhanced **for** loop. Here is a reworked version of the program that shows this technique:

```java
// Use iterators with a Hashtable.
import java.util.*;

class HTDemo2 {
    public static void main(String args[]) {
        Hashtable<String, Double> balance =
            new Hashtable<String, Double>();

        String str;
        double bal;
```
Properties

Properties is a subclass of Hashtable. It is used to maintain lists of values in which the key is a String and the value is also a String. The Properties class is used by some other Java classes. For example, it is the type of object returned by System.getProperties() when obtaining environmental values. Although the Properties class, itself, is not generic, several of its methods are.

Properties defines the following protected instance variable:

Properties defaults;

This variable holds a default property list associated with a Properties object. Properties defines these constructors:
Properties( )
Properties(Properties propDefault)

The first version creates a Properties object that has no default values. The second creates an object that uses propDefault for its default values. In both cases, the property list is empty.

In addition to the methods that Properties inherits from Hashtable, Properties defines the methods listed in Table 19-20. Properties also contains one deprecated method: save( ). This was replaced by store( ) because save( ) did not handle errors correctly.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>String getProperty(String <em>key</em>)</td>
<td>Returns the value associated with <em>key</em>. A null object is returned if <em>key</em> is neither in the list nor in the default property list.</td>
</tr>
<tr>
<td>String getProperty(String <em>key</em>, String <em>defaultProperty</em>)</td>
<td>Returns the value associated with <em>key</em>. <em>defaultProperty</em> is returned if <em>key</em> is neither in the list nor in the default property list.</td>
</tr>
<tr>
<td>void list(PrintStream <em>streamOut</em>)</td>
<td>Sends the property list to the output stream linked to <em>streamOut</em>.</td>
</tr>
<tr>
<td>void list(PrintWriter <em>streamOut</em>)</td>
<td>Sends the property list to the output stream linked to <em>streamOut</em>.</td>
</tr>
<tr>
<td>void load(InputStream <em>streamIn</em>, throws IOException)</td>
<td>Inputs a property list from the input stream linked to <em>streamIn</em>.</td>
</tr>
<tr>
<td>void load(Reader <em>streamIn</em>, throws IOException)</td>
<td>Inputs a property list from the input stream linked to <em>streamIn</em>.</td>
</tr>
<tr>
<td>void loadFromXML(InputStream <em>streamIn</em>, throws IOException, InvalidPropertiesFormatException)</td>
<td>Inputs a property list from an XML document linked to <em>streamIn</em>.</td>
</tr>
<tr>
<td>Enumeration&lt;?&gt;* propertyNames(*)</td>
<td>Returns an enumeration of the keys. This includes those keys found in the default property list, too.</td>
</tr>
<tr>
<td>Object setProperty(String <em>key</em>, String <em>value</em>)</td>
<td>Associates <em>value</em> with <em>key</em>. Returns the previous value associated with <em>key</em>, or returns null if no such association exists.</td>
</tr>
<tr>
<td>void store(OutputStream <em>streamOut</em>, String <em>description</em>, throws IOException)</td>
<td>After writing the string specified by <em>description</em>, the property list is written to the output stream <em>streamOut</em>.</td>
</tr>
<tr>
<td>void store(Writer <em>streamOut</em>, String <em>description</em>, throws IOException)</td>
<td>After writing the string specified by <em>description</em>, the property list is written to the output stream <em>streamOut</em>.</td>
</tr>
<tr>
<td>void storeToXML(OutputStream <em>streamOut</em>, String <em>description</em>, throws IOException)</td>
<td>The property list and the string specified by <em>description</em> is written as an XML document to <em>streamOut</em>.</td>
</tr>
<tr>
<td>void storeToXML(OutputStream <em>streamOut</em>, String <em>description</em>, String <em>enc</em>)</td>
<td>The property list and the string specified by <em>description</em> is written as an XML document to <em>streamOut</em> using the specified character encoding.</td>
</tr>
<tr>
<td>Set&lt;String&gt; stringPropertyNames(*)</td>
<td>Returns a set of keys.</td>
</tr>
</tbody>
</table>
One useful capability of the Properties class is that you can specify a default property that will be returned if no value is associated with a certain key. For example, a default value can be specified along with the key in the getProperty( ) method—such as getProperty("name", "default value"). If the "name" value is not found, then "default value" is returned. When you construct a Properties object, you can pass another instance of Properties to be used as the default properties for the new instance. In this case, if you call getProperty("foo") on a given Properties object, and "foo" does not exist, Java looks for "foo" in the default Properties object. This allows for arbitrary nesting of levels of default properties.

The following example demonstrates Properties. It creates a property list in which the keys are the names of states and the values are the names of their capitals. Notice that the attempt to find the capital for Florida includes a default value.
// Demonstrate a Property list.
import java.util.*;

class PropDemo {
    public static void main(String args[]) {
        Properties capitals = new Properties();

        capitals.put("Illinois", "Springfield");
        capitals.put("Missouri", "Jefferson City");
        capitals.put("Washington", "Olympia");
        capitals.put("California", "Sacramento");
        capitals.put("Indiana", "Indianapolis");

        // Get a set-view of the keys.
        Set<?> states = capitals.keySet();

        // Show all of the states and capitals.
        for(Object name : states)
            System.out.println("The capital of " + name + " is " + capitals.getProperty((String)name) + ".");

        System.out.println();

        // Look for state not in list -- specify default.
        String str = capitals.getProperty("Florida", "Not Found");
        System.out.println("The capital of Florida is " + str + ".");
    }
}

The output from this program is shown here:

    The capital of Missouri is Jefferson City.
    The capital of Illinois is Springfield.
    The capital of Indiana is Indianapolis.
    The capital of California is Sacramento.
    The capital of Washington is Olympia.

    The capital of Florida is Not Found.

Since Florida is not in the list, the default value is used.
Although it is perfectly valid to use a default value when you call getProperty(), as the preceding example shows, there is a better way of handling default values for
most applications of property lists. For greater flexibility, specify a default property list when constructing a `Properties` object. The default list will be searched if the desired key is not found in the main list. For example, the following is a slightly reworked version of the preceding program, with a default list of states specified. Now, when Florida is sought, it will be found in the default list:

```java
// Use a default property list.
import java.util.*;

class PropDemoDef {
   public static void main(String args[]) {
      Properties defList = new Properties();
      defList.put("Florida", "Tallahassee");
      defList.put("Wisconsin", "Madison");

      Properties capitals = new Properties(defList);

      capitals.put("Illinois", "Springfield");
      capitals.put("Missouri", "Jefferson City");
      capitals.put("Washington", "Olympia");
      capitals.put("California", "Sacramento");
      capitals.put("Indiana", "Indianapolis");

      // Get a set-view of the keys.
      Set<?> states = capitals.keySet();

      // Show all of the states and capitals.
      for(Object name : states)
         System.out.println("The capital of " +
                 name + " is " +
                 capitals.getProperty((String)name) + ".");

      System.out.println();

      // Florida will now be found in the default list.
      String str = capitals.getProperty("Florida");
      System.out.println("The capital of Florida is " + str + ".");
   }
}
```

Using `store()` and `load()`
One of the most useful aspects of Properties is that the information contained in a Properties object can be easily stored to or loaded from disk with the store() and load() methods. At any time, you can write a Properties object to a stream or read it back. This makes property lists especially convenient for implementing simple databases. For example, the following program uses a property list to create a simple computerized telephone book that stores names and phone numbers. To find a person’s number, you enter his or her name. The program uses the store() and load() methods to store and retrieve the list. When the program executes, it first tries to load the list from a file called phonebook.dat. If this file exists, the list is loaded. You can then add to the list. If you do, the new list is saved when you terminate the program. Notice how little code is required to implement a small, but functional, computerized phone book.

/* A simple telephone number database that uses a property list. */
import java.io.*;
import java.util.*;

class Phonebook {
    public static void main(String args[])
        throws IOException
    {
        Properties ht = new Properties();
        BufferedReader br =
            new BufferedReader(new InputStreamReader(System.in));
        String name, number;
        FileInputStream fin = null;
        boolean changed = false;

        // Try to open phonebook.dat file.
        try {
            fin = new FileInputStream("phonebook.dat");
        } catch(FileNotFoundException e) {
            // ignore missing file
        }
/* If phonebook file already exists, 
load existing telephone numbers. */
try {
    if (fin != null) {
        ht.load(fin);
        fin.close();
    }
} catch (IOException e) {
    System.out.println("Error reading file.");
}

// Let user enter new names and numbers.
do {
    System.out.println("Enter new name" +
                      " ('quit' to stop): ");
    name = br.readLine();
    if (name.equals("quit")) continue;

    System.out.println("Enter number: ");
    number = br.readLine();

    ht.put(name, number);
    changed = true;
} while (!name.equals("quit"));
// If phone book data has changed, save it.
if (changed) {
    FileOutputStream fout = new FileOutputStream("phonebook.dat");
    ht.store(fout, "Telephone Book");
    fout.close();
}

// Look up numbers given a name.
do {
    System.out.println("Enter name to find" +
                      " ('quit' to quit): ");
    name = br.readLine();
    if (name.equals("quit")) continue;

    number = (String) ht.get(name);
    System.out.println(number);
} while (!name.equals("quit"));


Parting Thoughts on Collections

The Collections Framework gives you, the programmer, a powerful set of well-engineered solutions to some of programming’s most common tasks. Consider using a collection the next time you need to store and retrieve information. Remember, collections need not be reserved for only the “large jobs,” such as corporate databases, mailing lists, or inventory systems. They are also effective when applied to smaller jobs. For example, a TreeMap might make an excellent collection to hold the directory structure of a set of files. A TreeSet could be quite useful for storing project-management information. Frankly, the types of problems that will benefit from a collections-based solution are limited only by your imagination. One last point: In Chapter 29, the new stream API is discussed. Because streams are now integrated with collections, consider using a stream when operating on a collection.
CHAPTER
20 java.util Part 2: More Utility Classes

This chapter continues our discussion of java.util by examining those classes and interfaces that are not part of the Collections Framework. These include classes that tokenize strings, work with dates, compute random numbers, and bundle resources. Also covered are the Formatter and Scanner classes which make it easy to write and read formatted data, and the Optional class, which simplifies handling situations in which a value may be absent. Finally, the subpackages of java.util are summarized at the end of this chapter. Of particular interest is java.util.function, which defines several standard functional interfaces. One last point: the Observer interface and the Observable class packaged in java.util. have been deprecated by JDK 9. For this reason they are not discussed here.

StringTokenizer

The processing of text often consists of parsing a formatted input string. Parsing is the division of text into a set of discrete parts, or tokens, which in a certain sequence can convey a semantic meaning. The StringTokenizer class provides the first step in this parsing process, often called the lexer (lexical analyzer) or scanner. StringTokenizer implements the Enumeration interface. Therefore, given an input string, you can enumerate the individual tokens contained in it using StringTokenizer. Before we begin, it is important to point out that StringTokenizer is described here primarily for the benefit of those programmers working with legacy code. For new code, regular expressions, discussed in Chapter 30, offer a more modern alternative.

To use StringTokenizer, you specify an input string and a string that contains delimiters. Delimiters are characters that separate tokens. Each character in the delimiters string is considered a valid delimiter—for example, ",;:" sets the delimiters to a comma, semicolon, and colon. The default set of delimiters consists of the whitespace characters: space, tab, form feed, newline, and carriage return.

The StringTokenizer constructors are shown here:

StringTokenizer(String str)
StringTokenizer(String `str`, String `delimiters`)  
StringTokenizer(String `str`, String `delimiters`, boolean `delimAsToken`)  

In all versions, `str` is the string that will be tokenized. In the first version, the default delimiters are used. In the second and third versions, `delimiters` is a string that specifies the delimiters. In the third version, if `delimAsToken` is `true`, then the delimiters are also returned as tokens when the string is parsed. Otherwise, the delimiters are not returned. Delimiters are not returned as tokens by the first two forms.

Once you have created a `StringTokenizer` object, the `nextToken()` method is used to extract consecutive tokens. The `hasMoreTokens()` method returns `true` while there are more tokens to be extracted. Since `StringTokenizer` implements `Enumeration`, the `hasMoreElements()` and `nextElement()` methods are also implemented, and they act the same as `hasMoreTokens()` and `nextToken()`, respectively. The `StringTokenizer` methods are shown in Table 20-1.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>int countTokens()</code></td>
<td>Using the current set of delimiters, the method determines the number of tokens left to be parsed and returns the result.</td>
</tr>
<tr>
<td><code>boolean hasMoreElements()</code></td>
<td>Returns <code>true</code> if one or more tokens remain in the string and returns <code>false</code> if there are none.</td>
</tr>
<tr>
<td><code>boolean hasMoreTokens()</code></td>
<td>Returns <code>true</code> if one or more tokens remain in the string and returns <code>false</code> if there are none.</td>
</tr>
<tr>
<td><code>Object nextElement()</code></td>
<td>Returns the next token as an <code>Object</code>.</td>
</tr>
<tr>
<td><code>String nextToken()</code></td>
<td>Returns the next token as a <code>String</code>.</td>
</tr>
<tr>
<td><code>String nextToken(String </code>delimiters<code>)</code></td>
<td>Returns the next token as a <code>String</code> and sets the delimiters string to that specified by <code>delimiters</code>.</td>
</tr>
</tbody>
</table>

Table 20-1  The Methods Defined by `StringTokenizer`

Here is an example that creates a `StringTokenizer` to parse "key=value" pairs. Consecutive sets of "key=value" pairs are separated by a semicolon.
The output from this program is shown here:

title  Java: The Complete Reference
author  Schildt
publisher  Oracle Press
copyright  2018

**BitSet**

A **BitSet** class creates a special type of array that holds bit values in the form of **boolean** values. This array can increase in size as needed. This makes it similar to a vector of bits. The **BitSet** constructors are shown here:

```java
BitSet()
BitSet(int size)
```

The first version creates a default object. The second version allows you to specify its initial size (that is, the number of bits that it can hold). All bits are initialized to **false**.

**BitSet** defines the methods listed in Table 20-2.
<table>
<thead>
<tr>
<th><strong>Method</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void and(BitSet bitSet)</code></td>
<td>ANDs the contents of the invoking <code>BitSet</code> object with those specified by <code>bitSet</code>. The result is placed into the invoking object.</td>
</tr>
<tr>
<td><code>void andNot(BitSet bitSet)</code></td>
<td>For each set bit in <code>bitSet</code>, the corresponding bit in the invoking <code>BitSet</code> is cleared.</td>
</tr>
<tr>
<td><code>int cardinality()</code></td>
<td>Returns the number of set bits in the invoking object.</td>
</tr>
<tr>
<td><code>void clear()</code></td>
<td>Zeros all bits.</td>
</tr>
<tr>
<td><code>void clear(int index)</code></td>
<td>Zeros the bit specified by <code>index</code>.</td>
</tr>
<tr>
<td><code>void clear(int startIndex, int endIndex)</code></td>
<td>Zeros the bits from <code>startIndex</code> to <code>endIndex</code> - 1.</td>
</tr>
<tr>
<td><code>Object clone()</code></td>
<td>Duplicates the invoking <code>BitSet</code> object.</td>
</tr>
<tr>
<td><code>boolean equals(Object bitSet)</code></td>
<td>Returns <code>true</code> if the invoking bit set is equivalent to the one passed in <code>bitSet</code>. Otherwise, the method returns <code>false</code>.</td>
</tr>
<tr>
<td><code>void flip(int index)</code></td>
<td>Reverses the bit specified by <code>index</code>.</td>
</tr>
<tr>
<td><code>void flip(int startIndex, int endIndex)</code></td>
<td>Reverses the bits from <code>startIndex</code> to <code>endIndex</code> - 1.</td>
</tr>
<tr>
<td><code>boolean get(int index)</code></td>
<td>Returns the current state of the bit at the specified index.</td>
</tr>
<tr>
<td><code>BitSet get(int startIndex, int endIndex)</code></td>
<td>Returns a <code>BitSet</code> that consists of the bits from <code>startIndex</code> to <code>endIndex</code> - 1. The invoking object is not changed.</td>
</tr>
<tr>
<td><code>int hashCode()</code></td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td><code>boolean intersects(BitSet bitSet)</code></td>
<td>Returns <code>true</code> if at least one pair of corresponding bits within the invoking object and <code>bitSet</code> are set.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>boolean isEmpty()</td>
<td>Returns <code>true</code> if all bits in the invoking object are cleared.</td>
</tr>
<tr>
<td>int length()</td>
<td>Returns the number of bits required to hold the contents of the invoking <code>BitSet</code>. This value is determined by the location of the last set bit.</td>
</tr>
<tr>
<td>int nextClearBit(int startIndex)</td>
<td>Returns the index of the next cleared bit (that is, the next <code>false</code> bit), starting from the index specified by <code>startIndex</code>.</td>
</tr>
<tr>
<td>int nextSetBit(int startIndex)</td>
<td>Returns the index of the next set bit (that is, the next <code>true</code> bit), starting from the index specified by <code>startIndex</code>. If no bit is set, -1 is returned.</td>
</tr>
<tr>
<td>void or(BitSet bitSet)</td>
<td>ORs the contents of the invoking <code>BitSet</code> object with that specified by <code>bitSet</code>. The result is placed into the invoking object.</td>
</tr>
<tr>
<td>int previousClearBit(int startIndex)</td>
<td>Returns the index of the next cleared bit (that is, the next <code>false</code> bit) at or prior to the index specified by <code>startIndex</code>. If no cleared bit is found, -1 is returned.</td>
</tr>
<tr>
<td>int previousSetBit(int startIndex)</td>
<td>Returns the index of the next set bit (that is, the next <code>true</code> bit) at or prior to the index specified by <code>startIndex</code>. If no set bit is found, -1 is returned.</td>
</tr>
<tr>
<td>void set(int index)</td>
<td>Sets the bit specified by <code>index</code>.</td>
</tr>
<tr>
<td>void set(int index, boolean v)</td>
<td>Sets the bit specified by <code>index</code> to the value passed in <code>v</code>. <code>true</code> sets the bit; <code>false</code> clears the bit.</td>
</tr>
<tr>
<td>void set(int startIndex, int endIndex)</td>
<td>Sets the bits from <code>startIndex</code> to <code>endIndex-1</code>.</td>
</tr>
<tr>
<td>void set(int startIndex, int endIndex, boolean v)</td>
<td>Sets the bits from <code>startIndex</code> to <code>endIndex-1</code> to the value passed in <code>v</code>. <code>true</code> sets the bits; <code>false</code> clears the bits.</td>
</tr>
<tr>
<td>int size()</td>
<td>Returns the number of bits in the invoking <code>BitSet</code> object.</td>
</tr>
<tr>
<td>IntStream stream()</td>
<td>Returns a stream that contains the bit positions, from low to high, that have set bits.</td>
</tr>
<tr>
<td>byte[] toByteArray()</td>
<td>Returns a <code>byte</code> array that contains the invoking <code>BitSet</code> object.</td>
</tr>
<tr>
<td>long[] toLongArray()</td>
<td>Returns a <code>long</code> array that contains the invoking <code>BitSet</code> object.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Returns the string equivalent of the invoking <code>BitSet</code> object.</td>
</tr>
<tr>
<td>static BitSet valueOf(byte[] v)</td>
<td>Returns a <code>BitSet</code> that contains the bits in <code>v</code>.</td>
</tr>
<tr>
<td>static BitSet valueOf(ByteBuffer v)</td>
<td>Returns a <code>BitSet</code> that contains the bits in <code>v</code>.</td>
</tr>
<tr>
<td>static BitSet valueOf(long[] v)</td>
<td>Returns a <code>BitSet</code> that contains the bits in <code>v</code>.</td>
</tr>
<tr>
<td>static BitSet valueOf(LongBuffer v)</td>
<td>Returns a <code>BitSet</code> that contains the bits in <code>v</code>.</td>
</tr>
<tr>
<td>void xor(BitSet bitSet)</td>
<td>XORs the contents of the invoking <code>BitSet</code> object with that specified by <code>bitSet</code>. The result is placed into the invoking object.</td>
</tr>
</tbody>
</table>
Here is an example that demonstrates **BitSet**:

```java
// BitSet Demonstration.
import java.util.BitSet;

class BitSetDemo {
    public static void main(String args[]) {
        BitSet bits1 = new BitSet(16);
        BitSet bits2 = new BitSet(16);

        // set some bits
        for(int i=0; i<16; i++) {
            if((i%2) == 0) bits1.set(i);
            if((i%5) != 0) bits2.set(i);
        }

        System.out.println("Initial pattern in bits1: ");
        System.out.println(bits1);
        System.out.println("\nInitial pattern in bits2: ");
        System.out.println(bits2);

        // AND bits
        bits2.and(bits1);
        System.out.println("\nbits2 AND bits1: ");
        System.out.println(bits2);

        // OR bits
        bits2.or(bits1);
        System.out.println("\nbits2 OR bits1: ");
        System.out.println(bits2);

        // XOR bits
        bits2.xor(bits1);
        System.out.println("\nbits2 XOR bits1: ");
        System.out.println(bits2);
    }
}
```

The output from this program is shown here. When `toString()` converts a **BitSet** object to its string equivalent, each set bit is represented by its bit position. Cleared bits are not shown.
Beginning with JDK 8, the classes called Optional, OptionalDouble, OptionalInt, and OptionalLong offer a way to handle situations in which a value may or may not be present. In the past, you would normally use the value null to indicate that no value is present. However, this can lead to null pointer exceptions if an attempt is made to dereference a null reference. As a result, frequent checks for a null value were necessary to avoid generating an exception. These classes provide a better way to handle such situations. One other point: These classes are value-based; as such they are immutable and various restrictions apply, such as not using instances for synchronization and avoiding any use of reference equality. Consult the Oracle documentation for the latest details on value-based classes.

The first and most general of these classes is Optional. For this reason, it is the primary focus of this discussion. It is shown here:

```java
class Optional<T>
```

Here, T specifies the type of value stored. It is important to understand that an Optional instance can either contain a value of type T or be empty. In other words, an Optional object does not necessarily contain a value. Optional does not define any constructors, but it does define several methods that let you work with Optional objects. For example, you can determine if a value is present, obtain the value if it is present, obtain a default value when no value is present, and construct an Optional value. The Optional methods are shown in Table 20-3.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static (&lt;T&gt;) Optional(&lt;T&gt;) empty( )</td>
<td>Returns an object for which <code>isPresent()</code> returns <code>false</code>.</td>
</tr>
<tr>
<td>boolean equals(Object <code>optional</code>)</td>
<td>Returns <code>true</code> if the invoking object equals <code>optional</code>. Otherwise, returns <code>false</code>.</td>
</tr>
<tr>
<td>Optional(&lt;T&gt;) filter(Predicate(&lt;\text{? super T}&gt;) <code>condition</code>)</td>
<td>Returns an <code>Optional</code> instance that contains the same value as the invoking object if that value satisfies <code>condition</code>. Otherwise, an empty object is returned.</td>
</tr>
<tr>
<td>U Optional(&lt;U&gt;) flatMap(Function(&lt;\text{? super T},\text{Optional(&lt;U&gt;)&gt;}) <code>mapFunc</code>)</td>
<td>Applies the mapping function specified by <code>mapFunc</code> to the invoking object if that object contains a value and returns the result. Returns an empty object otherwise.</td>
</tr>
<tr>
<td>T <code>get()</code></td>
<td>Returns the value in the invoking object. However, if no value is present, <code>NoSuchElementException</code> is thrown.</td>
</tr>
<tr>
<td>int <code>hashCode()</code></td>
<td>Returns a hashcode for the value in invoking object. Returns 0 if there is no value.</td>
</tr>
<tr>
<td>void <code>ifPresent(Consumer&lt;\text{? super T}&gt; </code>func<code>)</code></td>
<td>Calls <code>func</code> if a value is present in the invoking object, passing the object to <code>func</code>. If no value is present, no action occurs.</td>
</tr>
<tr>
<td>void <code>ifPresentOrElse(Consumer&lt;\text{? super T}&gt; </code>func<code>, Runnable </code>onEmpty<code>)</code></td>
<td>Calls <code>func</code> if a value is present in the invoking object, passing the object to <code>func</code>. If no value is present, <code>onEmpty</code> will be executed. (Added by JDK 9.)</td>
</tr>
</tbody>
</table>
The best way to understand **Optional** is to work through an example that uses its core methods. At the foundation of **Optional** are **isPresent()** and **get()**. You can determine if a value is present by calling **isPresent()**. If a value is available, it will return **true**. Otherwise, **false** is returned. If a value is present in an **Optional** instance, you can obtain it by calling **get()**. However, if you call **get()** on an object that does not contain a value, **NoSuchElementException** is thrown. For this reason, you should always first confirm that a value is present before calling **get()** on an **Optional** object.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>boolean isPresent()</strong></td>
<td>Returns <strong>true</strong> if the invoking object contains a value. Returns <strong>false</strong> if no value is present.</td>
</tr>
<tr>
<td><strong>U Optional&lt;U&gt; map(Function&lt;? super T, ? extends U&gt; mapFunc)</strong></td>
<td>Applies the mapping function specified by <strong>mapFunc</strong> to the invoking object if that object contains a value and returns the result. Returns an empty object otherwise.</td>
</tr>
<tr>
<td><strong>static &lt;T&gt; Optional&lt;T&gt; of(T val)</strong></td>
<td>Creates an <strong>Optional</strong> instance that contains <strong>val</strong> and returns the result. The value of <strong>val</strong> must not be <strong>null</strong>.</td>
</tr>
<tr>
<td><strong>static &lt;T&gt; Optional&lt;T&gt; ofNullable(T val)</strong></td>
<td>Creates an <strong>Optional</strong> instance that contains <strong>val</strong> and returns the result. However, if <strong>val</strong> is <strong>null</strong>, then an empty <strong>Optional</strong> instance is returned.</td>
</tr>
<tr>
<td><strong>Optional&lt;T&gt; or(Supplier&lt;? extends T&gt; func)</strong></td>
<td>If no value is present in the invoking object, calls <strong>func</strong> to construct and return an <strong>Optional</strong> instance that contains a value. Otherwise, returns an <strong>Optional</strong> instance that contains the invoking object’s value. (Added by JDK 9.)</td>
</tr>
<tr>
<td><strong>T orElse(T defVal)</strong></td>
<td>If the invoking object contains a value, the value is returned. Otherwise, the value specified by <strong>defVal</strong> is returned.</td>
</tr>
<tr>
<td><strong>T orElseGet(Supplier&lt;? extends T&gt; getFunc)</strong></td>
<td>If the invoking object contains a value, the value is returned. Otherwise, the value obtained from <strong>getFunc</strong> is returned.</td>
</tr>
<tr>
<td><strong>&lt;X extends Throwable&gt; T orElseThrow(Supplier&lt;? extends X&gt; excFunc) throws X</strong></td>
<td>Returns the value in the invoking object. However, if no value is present, the exception generated by <strong>excFunc</strong> is thrown.</td>
</tr>
<tr>
<td><strong>Stream&lt;T&gt; stream()</strong></td>
<td>Returns a stream that contains the invoking object’s value. If no value is present, the stream will contain no values. (Added by JDK 9.)</td>
</tr>
<tr>
<td><strong>String toString()</strong></td>
<td>Returns a string corresponding to the invoking object.</td>
</tr>
</tbody>
</table>

**Table 20-3 The Methods Defined by Optional**
Of course, having to call two methods to retrieve a value adds overhead to each access. Fortunately, `Optional` defines methods that combine the check for a value with the retrieval of the value. One such method is `orElse()`. If the object on which it is called contains a value, the value is returned. Otherwise, a default value is returned.

`Optional` does not define any constructors. Instead, you will use one of its methods to create an instance. For example, you can create an `Optional` instance with a specified value by using `of()`. You can create an instance of `Optional` that does not contain a value by using `empty()`.

The following program demonstrates these methods:

```java
// Demonstrate several Optional<T> methods
import java.util.*;

class OptionalDemo {
    public static void main(String args[]) {

        Optional<String> noVal = Optional.empty();

        Optional<String> hasVal = Optional.of("ABCDEFG");

        if(noVal.isPresent()) System.out.println("This won't be displayed");
        else System.out.println("noVal has no value");

        if(hasVal.isPresent()) System.out.println("The string in hasVal is: " + hasVal.get());

        String defStr = noVal.orElse("Default String");
        System.out.println(defStr);
    }
}
```

The output is shown here:

```
noVal has no value
The string in hasVal is: ABCDEFG
Default String
```

As the output shows, a value can be obtained from an `Optional` object only if one is present. This basic mechanism enables `Optional` to prevent null pointer exceptions.

The `OptionalDouble`, `OptionalInt`, and `OptionalLong` classes work much like
Optional, except that they are designed expressly for use on double, int, and long values, respectively. As such, they specify the methodsgetAsDouble(), getAsInt(), andgetAsLong(), respectively, rather than get(). Also, they do not support the filter(), ofNullable(), map(), flatMap(), and or() methods.

Date

The Date class encapsulates the current date and time. Before beginning our examination of Date, it is important to point out that it has changed substantially from its original version defined by Java 1.0. When Java 1.1 was released, many of the functions carried out by the original Date class were moved into the Calendar and DateFormat classes, and as a result, many of the original 1.0 Date methods were deprecated. Since the deprecated 1.0 methods should not be used for new code, they are not described here.

Date supports the following non-deprecated constructors:

Date()
Date(long millisec)

The first constructor initializes the object with the current date and time. The second constructor accepts one argument that equals the number of milliseconds that have elapsed since midnight, January 1, 1970. The non-deprecated methods defined by Date are shown in Table 20-4. Date also implements the Comparable interface.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean after(Date date)</td>
<td>Returns <strong>true</strong> if the invoking <code>Date</code> object contains a date that is later than the one specified by <code>date</code>. Otherwise, it returns <strong>false</strong>.</td>
</tr>
<tr>
<td>boolean before(Date date)</td>
<td>Returns <strong>true</strong> if the invoking <code>Date</code> object contains a date that is earlier than the one specified by <code>date</code>. Otherwise, it returns <strong>false</strong>.</td>
</tr>
<tr>
<td>Object clone()</td>
<td>Duplicates the invoking <code>Date</code> object.</td>
</tr>
<tr>
<td>int compareTo(Date date)</td>
<td>Compares the value of the invoking object with that of <code>date</code>. Returns 0 if the values are equal. Returns a negative value if the invoking object is earlier than <code>date</code>. Returns a positive value if the invoking object is later than <code>date</code>.</td>
</tr>
<tr>
<td>boolean equals(Object date)</td>
<td>Returns <strong>true</strong> if the invoking <code>Date</code> object contains the same time and date as the one specified by <code>date</code>. Otherwise, it returns <strong>false</strong>.</td>
</tr>
<tr>
<td>static Date from(Instant t)</td>
<td>Returns a <code>Date</code> object corresponding to the <code>Instant</code> object passed in <code>t</code>.</td>
</tr>
<tr>
<td>long getTime()</td>
<td>Returns the number of milliseconds that have elapsed since January 1, 1970.</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns a hash code for the invoking object.</td>
</tr>
<tr>
<td>void setTime(long time)</td>
<td>Sets the time and date as specified by <code>time</code>, which represents an elapsed time in milliseconds from midnight, January 1, 1970.</td>
</tr>
<tr>
<td>Instant toInstant()</td>
<td>Returns an <code>Instant</code> object corresponding to the invoking <code>Date</code> object.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Converts the invoking <code>Date</code> object into a string and returns the result.</td>
</tr>
</tbody>
</table>

Table 20-4  The Nondeprecated Methods Defined by `Date`

As you can see by examining Table 20-4, the non-deprecated `Date` features do not allow you to obtain the individual components of the date or time. As the following program demonstrates, you can only obtain the date and time in terms of milliseconds, in its default string representation as returned by `toString()`, or as an `Instant` object. To obtain more-detailed information about the date and time, you will use the `Calendar` class.
Calendar

The abstract Calendar class provides a set of methods that allows you to convert a time in milliseconds to a number of useful components. Some examples of the type of information that can be provided are year, month, day, hour, minute, and second. It is intended that subclasses of Calendar will provide the specific functionality to interpret time information according to their own rules. This is one aspect of the Java class library that enables you to write programs that can operate in international environments. An example of such a subclass is GregorianCalendar.

NOTE JDK 8 defined a new date and time API in java.time, which new applications may want to employ. See Chapter 30.

Calendar provides no public constructors. Calendar defines several protected instance variables. areFieldsSet is a boolean that indicates if the time components have been set. fields is an array of ints that holds the components of the time. isSet is a boolean array that indicates if a specific time component has been set. time is a long that holds the current time for this object. isTimeSet is a boolean that indicates if the current time has been set.

A sampling of methods defined by Calendar are shown in Table 20-5.

```java
// Show date and time using only Date methods.
import java.util.Date;

class DateDemo {
    public static void main(String args[]) {
        // Instantiate a Date object
        Date date = new Date();

        // display time and date using toString()
        System.out.println(date);

        // Display number of milliseconds since midnight, January:
        long msec = date.getTime();
        System.out.println("Milliseconds since Jan. 1, 1970 GMT = ");
    }
}

Sample output is shown here:

Sun Jan 01 11:11:44 CST 2017
Milliseconds since Jan. 1, 1970 GMT = 1483302217158
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>abstract void add(int <em>which</em>, int <em>val</em>)</td>
<td>Adds <em>val</em> to the time or date component specified by <em>which</em>. To subtract, add a negative value. <em>which</em> must be one of the fields defined by Calendar, such as Calendar.HOUR.</td>
</tr>
<tr>
<td>boolean after(Object <em>calendarObj</em>)</td>
<td>Returns true if the invoking Calendar object contains a date that is later than the one specified by <em>calendarObj</em>. Otherwise, it returns false.</td>
</tr>
<tr>
<td>boolean before(Object <em>calendarObj</em>)</td>
<td>Returns true if the invoking Calendar object contains a date that is earlier than the one specified by <em>calendarObj</em>. Otherwise, it returns false.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>final void clear()</td>
<td>Zeros all time components in the invoking object.</td>
</tr>
<tr>
<td>final void clear(int which)</td>
<td>Zeros the time component specified by which in the invoking object.</td>
</tr>
<tr>
<td>Object clone()</td>
<td>Returns a duplicate of the invoking object.</td>
</tr>
<tr>
<td>boolean equals(Object calendarObj)</td>
<td>Returns true if the invoking Calendar object contains a date that is equal to the one specified by calendarObj. Otherwise, it returns false.</td>
</tr>
<tr>
<td>int get(int calendarField)</td>
<td>Returns the value of one component of the invoking object. The component is indicated by calendarField. Examples of the components that can be requested are Calendar.YEAR, Calendar.MONTH, Calendar.MINUTE, and so forth.</td>
</tr>
<tr>
<td>static Locale[] getAvailableLocales()</td>
<td>Returns an array of Locale objects that contains the locales for which calendars are available.</td>
</tr>
<tr>
<td>static Calendar getInstance()</td>
<td>Returns a Calendar object for the default locale and time zone.</td>
</tr>
<tr>
<td>static Calendar getInstance(TimeZone tz)</td>
<td>Returns a Calendar object for the time zone specified by tz. The default locale is used.</td>
</tr>
<tr>
<td>static Calendar getInstance(Locale locale)</td>
<td>Returns a Calendar object for the locale specified by locale. The default time zone is used.</td>
</tr>
<tr>
<td>static Calendar getInstance(TimeZone tz, Locale locale)</td>
<td>Returns a Calendar object for the time zone specified by tz and the locale specified by locale.</td>
</tr>
<tr>
<td>final Date getTime()</td>
<td>Returns a Date object equivalent to the time of the invoking object.</td>
</tr>
<tr>
<td>TimeZone getTimeZone()</td>
<td>Returns the time zone for the invoking object.</td>
</tr>
<tr>
<td>final boolean isSet(int which)</td>
<td>Returns true if the specified time component is set. Otherwise, it returns false.</td>
</tr>
<tr>
<td>void set(int which, int val)</td>
<td>Sets the date or time component specified by which to the value specified by val in the invoking object. which must be one of the fields defined by Calendar, such as Calendar.HOUR.</td>
</tr>
<tr>
<td>final void set(int year, int month, int dayOfMonth)</td>
<td>Sets various date and time components of the invoking object.</td>
</tr>
<tr>
<td>final void set(int year, int month, int dayOfMonth, int hours, int minutes)</td>
<td>Sets various date and time components of the invoking object.</td>
</tr>
<tr>
<td>final void set(int year, int month, int dayOfMonth, int hours, int minutes, int seconds)</td>
<td>Sets various date and time components of the invoking object.</td>
</tr>
</tbody>
</table>
Table 20-5  A Sampling of the Methods Defined by Calendar

Calendar defines the following int constants, which are used when you get or set components of the calendar.

<table>
<thead>
<tr>
<th>ALL_STYLES</th>
<th>HOUR_OF_DAY</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM</td>
<td>JANUARY</td>
<td>SATURDAY</td>
</tr>
<tr>
<td>AM_PM</td>
<td>JULY</td>
<td>SECOND</td>
</tr>
<tr>
<td>APRIL</td>
<td>JUNE</td>
<td>SEPTEMBER</td>
</tr>
<tr>
<td>AUGUST</td>
<td>LONG</td>
<td>SHORT</td>
</tr>
<tr>
<td>DATE</td>
<td>LONG_FORMAT</td>
<td>SHORT_FORMAT</td>
</tr>
<tr>
<td>DAY_OF_MONTH</td>
<td>LONG_STANDALONE</td>
<td>SHORT_STANDALONE</td>
</tr>
<tr>
<td>DAY_OF_WEEK</td>
<td>MARCH</td>
<td>SUNDAY</td>
</tr>
<tr>
<td>DAY_OF_WEEK_IN_MONTH</td>
<td>MAY</td>
<td>THURSDAY</td>
</tr>
<tr>
<td>DAY_OF_YEAR</td>
<td>MILLISECOND</td>
<td>TUESDAY</td>
</tr>
<tr>
<td>DECEMBER</td>
<td>MINUTE</td>
<td>UNDECEMBER</td>
</tr>
<tr>
<td>DST_OFFSET</td>
<td>MONDAY</td>
<td>WEDNESDAY</td>
</tr>
<tr>
<td>ERA</td>
<td>MONTH</td>
<td>WEEK_OF_MONTH</td>
</tr>
<tr>
<td>FEBRUARY</td>
<td>NARROW_FORMAT</td>
<td>WEEK_OF_YEAR</td>
</tr>
<tr>
<td>FIELD_COUNT</td>
<td>NARROW_STANDALONE</td>
<td>YEAR</td>
</tr>
<tr>
<td>FRIDAY</td>
<td>NOVEMBER</td>
<td>ZONE_OFFSET</td>
</tr>
<tr>
<td>HOUR</td>
<td>OCTOBER</td>
<td></td>
</tr>
</tbody>
</table>

The following program demonstrates several Calendar methods:
// Demonstrate Calendar
import java.util.Calendar;

class CalendarDemo {
    public static void main(String args[]) {
        String months[] = {
            "Jan", "Feb", "Mar", "Apr",
            "May", "Jun", "Jul", "Aug",
            "Sep", "Oct", "Nov", "Dec"};

        // Create a calendar initialized with the
        // current date and time in the default
        // locale and timezone.
        Calendar calendar = Calendar.getInstance();

        // Display current time and date information.
        System.out.print("Date: ");
        System.out.print(months[calendar.get(Calendar.MONTH)]);
        System.out.print(" " + calendar.get(Calendar.DATE) + " ");
        System.out.println(calendar.get(Calendar.YEAR));

        System.out.print("Time: ");
        System.out.print(calendar.get(Calendar.HOUR) + ":" );
        System.out.print(calendar.get(Calendar.MINUTE) + ":" );
        System.out.println(calendar.get(Calendar.SECOND));

        // Set the time and date information and display it.
        calendar.set(Calendar.HOUR, 10);
        calendar.set(Calendar.MINUTE, 29);
        calendar.set(Calendar.SECOND, 22);
        System.out.print("Updated time: ");
        System.out.print(calendar.get(Calendar.HOUR) + ":" );
        System.out.print(calendar.get(Calendar.MINUTE) + ":" );
        System.out.println(calendar.get(Calendar.SECOND));
    }
}

Sample output is shown here:

Date: Jan 1 2017
Time: 11:29:39
Updated time: 10:29:22

GregorianCalendar
**GregorianCalendar** is a concrete implementation of a **Calendar** that implements the normal Gregorian calendar with which you are familiar. The `getInstance()` method of `Calendar` will typically return a `GregorianCalendar` initialized with the current date and time in the default locale and time zone.

**GregorianCalendar** defines two fields: **AD** and **BC**. These represent the two eras defined by the Gregorian calendar.

There are also several constructors for `GregorianCalendar` objects. The default, `GregorianCalendar()`, initializes the object with the current date and time in the default locale and time zone. Three more constructors offer increasing levels of specificity:

```
GregorianCalendar(int year, int month, int dayOfMonth)
GregorianCalendar(int year, int month, int dayOfMonth, int hours, int minutes)
GregorianCalendar(int year, int month, int dayOfMonth, int hours, int minutes, int seconds)
```

All three versions set the day, month, and year. Here, `year` specifies the year. The month is specified by `month`, with zero indicating January. The day of the month is specified by `dayOfMonth`. The first version sets the time to midnight. The second version also sets the hours and the minutes. The third version adds seconds.

You can also construct a `GregorianCalendar` object by specifying the locale and/or time zone. The following constructors create objects initialized with the current date and time using the specified time zone and/or locale:

```
GregorianCalendar(Locale locale)
GregorianCalendar(TimeZone timeZone)
GregorianCalendar(TimeZone timeZone, Locale locale)
```

**GregorianCalendar** provides an implementation of all the abstract methods in `Calendar`. It also provides some additional methods. Perhaps the most interesting is `isLeapYear()`, which tests if the year is a leap year. Its form is

```
boolean isLeapYear(int year)
```

This method returns `true` if `year` is a leap year and `false` otherwise. Two other methods of interest are `from()` and `toZonedDateTime()`, which support the date and time API added by JDK 8.

The following program demonstrates `GregorianCalendar`: 

```java
GregorianCalendar
```
// Demonstrate GregorianCalendar
import java.util.*;

class GregorianCalendarDemo {
    public static void main(String args[]) {
        String months[] = {
            "Jan", "Feb", "Mar", "Apr",
            "May", "Jun", "Jul", "Aug",
            "Sep", "Oct", "Nov", "Dec"};
        int year;

        // Create a Gregorian calendar initialized
        // with the current date and time in the
        // default locale and timezone.
        GregorianCalendar gcalendar = new GregorianCalendar();

        // Display current time and date information.
        System.out.print("Date: ");
        System.out.print(months[gcalendar.get(Calendar.MONTH)]);
        System.out.print(" " + gcalendar.get(Calendar.DATE) + " ");
        System.out.println(year = gcalendar.get(Calendar.YEAR));

        System.out.print("Time: ");
        System.out.print(gcalendar.get(Calendar.HOUR) + ":");
        System.out.print(gcalendar.get(Calendar.MINUTE) + ":");
        System.out.println(gcalendar.get(Calendar.SECOND));

        // Test if the current year is a leap year
        if(gcalendar.isLeapYear(year)) {
            System.out.println("The current year is a leap year");
        } else {
            System.out.println("The current year is not a leap year");
        }
    }
}

Sample output is shown here:

    Date: Jan 1 2017
    Time: 1:45:5
    The current year is not a leap year
TimeZone

Another time-related class is **TimeZone**. The abstract **TimeZone** class allows you to work with time zone offsets from Greenwich mean time (GMT), also referred to as Coordinated Universal Time (UTC). It also computes daylight saving time. **TimeZone** only supplies the default constructor.

A sampling of methods defined by **TimeZone** is given in Table 20-6.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object clone( )</td>
<td>Returns a <strong>TimeZone</strong>-specific version of clone( ).</td>
</tr>
<tr>
<td>static String[ ] getAvailableIDs( )</td>
<td>Returns an array of <strong>String</strong> objects representing the names of all time zones.</td>
</tr>
<tr>
<td>static String[ ] getAvailableIDs(int timeDelta)</td>
<td>Returns an array of <strong>String</strong> objects representing the names of all time zones that are timeDelta offset from GMT.</td>
</tr>
<tr>
<td>static TimeZone getDefault( )</td>
<td>Returns a <strong>TimeZone</strong> object that represents the default time zone used on the host computer.</td>
</tr>
<tr>
<td>String getID( )</td>
<td>Returns the name of the invoking <strong>TimeZone</strong> object.</td>
</tr>
<tr>
<td>abstract int getOffset(int era, int year, int month, int dayOfMonth, int dayOfWeek, int millisec)</td>
<td>Returns the offset that should be added to GMT to compute local time. This value is adjusted for daylight saving time. The parameters to the method represent date and time components.</td>
</tr>
<tr>
<td>abstract int getRawOffset( )</td>
<td>Returns the raw offset (in milliseconds) that should be added to GMT to compute local time. This value is not adjusted for daylight saving time.</td>
</tr>
<tr>
<td>static TimeZone getTimeZone(String tzName)</td>
<td>Returns the <strong>TimeZone</strong> object for the time zone named tzName.</td>
</tr>
<tr>
<td>abstract boolean inDaylightTime(Date d)</td>
<td>Returns <strong>true</strong> if the date represented by d is in daylight saving time in the invoking object. Otherwise, it returns <strong>false</strong>.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>static void setDefault(TimeZone tz)</td>
<td>Sets the default time zone to be used on this host. tz is a reference to the TimeZone object to be used.</td>
</tr>
<tr>
<td>void setID(String tzName)</td>
<td>Sets the name of the time zone (that is, its ID) to that specified by tzName.</td>
</tr>
<tr>
<td>abstract void setRawOffset(int millis)</td>
<td>Sets the offset in milliseconds from GMT.</td>
</tr>
<tr>
<td>Zoneld toZoneld()</td>
<td>Converts the invoking object into a Zoneld and returns the result. Zoneld is packaged in java.time.</td>
</tr>
<tr>
<td>abstract boolean useDaylightTime()</td>
<td>Returns true if the invoking object uses daylight saving time. Otherwise, it returns false.</td>
</tr>
</tbody>
</table>

Table 20-6  A Sampling of the Methods Defined by TimeZone

**SimpleTimeZone**

The SimpleTimeZone class is a convenient subclass of TimeZone. It implements TimeZone's abstract methods and allows you to work with time zones for a Gregorian calendar. It also computes daylight saving time.

SimpleTimeZone defines four constructors. One is

SimpleTimeZone(int timeDelta, String tzName)

This constructor creates a SimpleTimeZone object. The offset relative to Greenwich mean time (GMT) is timeDelta. The time zone is named tzName.

The second SimpleTimeZone constructor is

SimpleTimeZone(int timeDelta, String tzId, int dstMonth0, int dstDayInMonth0, int dstDay0, int time0, int dstMonth1, int dstDayInMonth1, int dstDay1, int time1)

Here, the offset relative to GMT is specified in timeDelta. The time zone name is passed in tzId. The start of daylight saving time is indicated by the parameters dstMonth0, dstDayInMonth0, dstDay0, and time0. The end of daylight saving time is indicated by the parameters dstMonth1, dstDayInMonth1, dstDay1, and time1.

The third SimpleTimeZone constructor is

SimpleTimeZone(int timeDelta, String tzId, int dstMonth0, int dstDayInMonth0, int dstDay0, int time0, int dstMonth1, int dstDayInMonth1, int dstDay1, int time1, int dstDelta)
Here, $dstDelta$ is the number of milliseconds saved during daylight saving time.

The fourth SimpleTimeZone constructor is:

```java
SimpleTimeZone(int timeDelta, String tzId, int dstMonth0,
               int dstDayInMonth0, int dstDay0, int time0,
               int time0mode, int dstMonth1, int dstDayInMonth1,
               int dstDay1, int time1, int time1mode, int dstDelta)
```

Here, $time0mode$ specifies the mode of the starting time, and $time1mode$ specifies the mode of the ending time. Valid mode values include:

<table>
<thead>
<tr>
<th>STANDARD_TIME</th>
<th>WALL_TIME</th>
<th>UTC_TIME</th>
</tr>
</thead>
</table>

The time mode indicates how the time values are interpreted. The default mode used by the other constructors is WALL_TIME.

## Locale

The **Locale** class is instantiated to produce objects that describe a geographical or cultural region. It is one of several classes that provide you with the ability to write programs that can execute in different international environments. For example, the formats used to display dates, times, and numbers are different in various regions.

Internationalization is a large topic that is beyond the scope of this book. However, many programs will only need to deal with its basics, which include setting the current locale.

The **Locale** class defines the following constants that are useful for dealing with several common locales:

<table>
<thead>
<tr>
<th>CANADA</th>
<th>GERMAN</th>
<th>KOREAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>CANADA_FRENCH</td>
<td>GERMANY</td>
<td>PRC</td>
</tr>
<tr>
<td>CHINA</td>
<td>ITALIAN</td>
<td>SIMPLIFIED.CHINESE</td>
</tr>
<tr>
<td>CHINESE</td>
<td>ITALY</td>
<td>TAIWAN</td>
</tr>
<tr>
<td>ENGLISH</td>
<td>JAPAN</td>
<td>TRADITIONAL.CHINESE</td>
</tr>
<tr>
<td>FRANCE</td>
<td>JAPANESE</td>
<td>UK</td>
</tr>
<tr>
<td>FRENCH</td>
<td>KOREA</td>
<td>US</td>
</tr>
</tbody>
</table>

For example, the expression `Locale.CANADA` represents the **Locale** object for
Canada.

The constructors for **Locale** are

- `Locale(String language)`
- `Locale(String language, String country)`
- `Locale(String language, String country, String variant)`

These constructors build a **Locale** object to represent a specific *language* and in the case of the last two, *country*. These values must contain standard language and country codes. Auxiliary variant information can be provided in *variant*.

**Locale** defines several methods. One of the most important is `setDefault( )`, shown here:

```java
static void setDefault(Locale localeObj)
```

This sets the default locale used by the JVM to that specified by `localeObj`.

Some other interesting methods are the following:

```java
final String getDisplayCountry( )
final String getDisplayLanguage( )
final String getDisplayName( )
```

These return human-readable strings that can be used to display the name of the country, the name of the language, and the complete description of the locale.

The default locale can be obtained using `getDefault( )`, shown here:

```java
static Locale getDefault( )
```

JDK 7 added significant upgrades to the **Locale** class that support Internet Engineering Task Force (IETF) BCP 47, which defines tags for identifying languages, and Unicode Technical Standard (UTS) 35, which defines the Locale Data Markup Language (LDML). Support for BCP 47 and UTS 35 caused several features to be added to **Locale**, including several new methods and the **Locale.Builder** class. Among others, new methods include `getScript( )`, which obtains the locale’s script, and `toLanguageTag( )`, which obtains a string that contains the locale’s language tag. The **Locale.Builder** class constructs **Locale** instances. It ensures that a locale specification is well-formed as defined by BCP 47. (The **Locale** constructors do not provide such a check.) Several new methods were also added to **Locale** by JDK 8. Among these are methods that support filtering, extensions, and lookups. JDK 9 adds a method called `getISOCountries( )`, which
returns a collection of country codes for a given `Locale.IsoCountryCode` enumeration value.

`Calendar` and `GregorianCalendar` are examples of classes that operate in a locale-sensitive manner. `DateFormat` and `SimpleDateFormat` also depend on the locale.

### Random

The `Random` class is a generator of pseudorandom numbers. These are called *pseudorandom* numbers because they are simply uniformly distributed sequences. `Random` defines the following constructors:

- `Random()`
- `Random(long seed)`

The first version creates a number generator that uses a reasonably unique seed. The second form allows you to specify a seed value manually.

If you initialize a `Random` object with a seed, you define the starting point for the random sequence. If you use the same seed to initialize another `Random` object, you will extract the same random sequence. If you want to generate different sequences, specify different seed values. One way to do this is to use the current time to seed a `Random` object. This approach reduces the possibility of getting repeated sequences.

The core public methods defined by `Random` are shown in Table 20-7. These are the methods that have been available in `Random` for several years (many since Java 1.0) and are widely used.
As you can see, there are seven types of random numbers that you can extract from a `Random` object. Random Boolean values are available from `nextBoolean()` method. Random bytes can be obtained by calling `nextBytes( )`. Integers can be extracted via the `nextInt( )` method. Long integers can be obtained with `nextLong( )`. The `nextFloat( )` and `nextDouble( )` methods return `float` and `double` values, respectively, between 0.0 and 1.0. Finally, `nextGaussian( )` returns a `double` value centered at 0.0 with a standard deviation of 1.0. This is what is known as a bell curve.

Here is an example that demonstrates the sequence produced by `nextGaussian( )`. It obtains 100 random Gaussian values and averages these values. The program also counts the number of values that fall within two standard deviations, plus or minus, using increments of 0.5 for each category. The result is graphically displayed sideways on the screen.
Here is a sample program run. As you can see, a bell-like distribution of numbers is obtained.
JDK 8 added three methods to Random that support the stream API (see Chapter 29). They are called doubles(), ints(), and longs(), and each returns a reference to a stream that contains a sequence of pseudorandom values of the specified type. Each method defines several overloads. Here are their simplest forms:

```java
DoubleStream doubles()
IntStream ints()
LongStream longs()
```

The doubles() method returns a stream that contains pseudorandom double values. (The range of these values will be less than 1.0 but greater than or equal to 0.0.) The ints() method returns a stream that contains pseudorandom int values. The longs() method returns a stream that contains pseudorandom long values. For these three methods, the stream returned is effectively infinite. Several overloads of each method are provided that let you specify the size of the stream, an origin, and an upper bound.

## Timer and TimerTask

An interesting and useful feature offered by java.util is the ability to schedule a task for execution at some future time. The classes that support this are Timer and TimerTask. Using these classes, you can create a thread that runs in the background, waiting for a specific time. When the time arrives, the task linked to that thread is executed. Various options allow you to schedule a task for repeated execution, and to schedule a task to run on a specific date. Although it was always possible to manually create a task that would be executed at a specific time using the Thread class, Timer and TimerTask greatly simplify this process.

Timer and TimerTask work together. Timer is the class that you will use to schedule a task for execution. The task being scheduled must be an instance of
TimerTask. Thus, to schedule a task, you will first create a TimerTask object and then schedule it for execution using an instance of Timer.

TimerTask implements the Runnable interface; thus, it can be used to create a thread of execution. Its constructor is shown here:

protected TimerTask( )

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean cancel( )</td>
<td>Terminates the task. Returns true if an execution of the task is prevented. Otherwise, returns false.</td>
</tr>
<tr>
<td>abstract void run( )</td>
<td>Contains the code for the timer task.</td>
</tr>
<tr>
<td>long scheduledExecutionTime( )</td>
<td>Returns the time at which the last execution of the task was scheduled to have occurred.</td>
</tr>
</tbody>
</table>

**Table 20-8**  The Methods Defined by TimerTask

TimerTask defines the methods shown in Table 20-8. Notice that run( ) is abstract, which means that it must be overridden. The run( ) method, defined by the Runnable interface, contains the code that will be executed. Thus, the easiest way to create a timer task is to extend TimerTask and override run( ).

Once a task has been created, it is scheduled for execution by an object of type Timer. The constructors for Timer are shown here:

Timer( )
Timer(boolean DThread)
Timer(String tName)
Timer(String tName, boolean DThread)

The first version creates a Timer object that runs as a normal thread. The second uses a daemon thread if DThread is true. A daemon thread will execute only as long as the rest of the program continues to execute. The third and fourth constructors allow you to specify a name for the Timer thread. The methods defined by Timer are shown in Table 20-9.
Once a `Timer` has been created, you will schedule a task by calling `schedule()` on the `Timer` that you created. As Table 20-9 shows, there are several forms of `schedule()` which allow you to schedule tasks in a variety of ways.

If you create a non-daemon task, then you will want to call `cancel()` to end the task when your program ends. If you don’t do this, then your program may "hang" for a period of time.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void cancel()</code></td>
<td>Cancels the timer thread.</td>
</tr>
<tr>
<td><code>int purge()</code></td>
<td>Deletes canceled tasks from the timer’s queue.</td>
</tr>
<tr>
<td><code>void schedule(TimerTask TT, long wait)</code></td>
<td><code>TT</code> is scheduled for execution after the period passed in <code>wait</code> has elapsed. The <code>wait</code> parameter is specified in milliseconds.</td>
</tr>
<tr>
<td><code>void schedule(TimerTask TT, long wait, long repeat)</code></td>
<td><code>TT</code> is scheduled for execution after the period passed in <code>wait</code> has elapsed. The task is then executed repeatedly at the interval specified by <code>repeat</code>. Both <code>wait</code> and <code>repeat</code> are specified in milliseconds.</td>
</tr>
<tr>
<td><code>void schedule(TimerTask TT, Date target)</code></td>
<td><code>TT</code> is scheduled for execution at the time specified by <code>target</code>.</td>
</tr>
<tr>
<td><code>void schedule(TimerTask TT, Date target, long repeat)</code></td>
<td><code>TT</code> is scheduled for execution at the time specified by <code>target</code>. The task is then executed repeatedly at the interval passed in <code>repeat</code>. The <code>repeat</code> parameter is specified in milliseconds.</td>
</tr>
<tr>
<td><code>void scheduleAtFixedRate(TimerTask TT, long wait, long repeat)</code></td>
<td><code>TT</code> is scheduled for execution after the period passed in <code>wait</code> has elapsed. The task is then executed repeatedly at the interval specified by <code>repeat</code>. Both <code>wait</code> and <code>repeat</code> are specified in milliseconds. The time of each repetition is relative to the first execution, not the preceding execution. Thus, the overall rate of execution is fixed.</td>
</tr>
<tr>
<td><code>void scheduleAtFixedRate(TimerTask TT, Date target, long repeat)</code></td>
<td><code>TT</code> is scheduled for execution at the time specified by <code>target</code>. The task is then executed repeatedly at the interval passed in <code>repeat</code>. The <code>repeat</code> parameter is specified in milliseconds. The time of each repetition is relative to the first execution, not the preceding execution. Thus, the overall rate of execution is fixed.</td>
</tr>
</tbody>
</table>

Table 20-9  The Methods Defined by Timer
The following program demonstrates **Timer** and **TimerTask**. It defines a timer task whose `run()` method displays the message "Timer task executed." This task is scheduled to run once every half second after an initial delay of one second.

```java
// Demonstrate Timer and TimerTask.

import java.util.*;

class MyTimerTask extends TimerTask {
    public void run() {
        System.out.println("Timer task executed.");
    }
}

class TTest {
    public static void main(String args[]) {
        MyTimerTask myTask = new MyTimerTask();
        Timer myTimer = new Timer();

        /* Set an initial delay of 1 second,
        then repeat every half second.
        */
        myTimer.schedule(myTask, 1000, 500);

        try {
            Thread.sleep(5000);
        } catch (InterruptedException exc) {}

        myTimer.cancel();
    }
}
```

### Currency

The **Currency** class encapsulates information about a currency. It defines no constructors. The methods supported by **Currency** are shown in Table 20-10. The following program demonstrates **Currency**:
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static Set.Currency getAvailableCurrencies()</td>
<td>Returns a set of the supported currencies.</td>
</tr>
<tr>
<td>String getCurrencyCode()</td>
<td>Returns the code (as defined by ISO 4217) that describes the invoking currency.</td>
</tr>
<tr>
<td>int getDefaultFractionDigits()</td>
<td>Returns the number of digits after the decimal point that are normally used by the invoking currency. For example, there are two fractional digits normally used for dollars.</td>
</tr>
<tr>
<td>String getDisplayName()</td>
<td>Returns the name of the invoking currency for the default locale.</td>
</tr>
<tr>
<td>String getDisplayName(Locale loc)</td>
<td>Returns the name of the invoking currency for the specified locale.</td>
</tr>
<tr>
<td>static Currency getInstance(Locale localeObj)</td>
<td>Returns a Currency object for the locale specified by localeObj.</td>
</tr>
<tr>
<td>static Currency getInstance(String code)</td>
<td>Returns a Currency object associated with the currency code passed in code.</td>
</tr>
<tr>
<td>int getNumericCode()</td>
<td>Returns the numeric code (as defined by ISO 4217) for the invoking currency.</td>
</tr>
<tr>
<td>String getNumericCodeAsString()</td>
<td>Returns in string form the numeric code (as defined by ISO 4217) for the invoking currency. (Added by JDK 9.)</td>
</tr>
<tr>
<td>String getSymbol()</td>
<td>Returns the currency symbol (such as $) for the invoking object.</td>
</tr>
<tr>
<td>String getSymbol(Locale localeObj)</td>
<td>Returns the currency symbol (such as $) for the locale passed in localeObj.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Returns the currency code for the invoking object.</td>
</tr>
</tbody>
</table>

**Table 20-10** The Methods Defined by Currency
// Demonstrate Currency.
import java.util.*;

class CurDemo {
    public static void main(String args[]) {
        Currency c;

        c = Currency.getInstance(Locale.US);

        System.out.println("Symbol: " + c.getSymbol());
        System.out.println("Default fractional digits: " + c.getDefaultFractionDigits());
    }
}

The output is shown here:
Symbol: $
Default fractional digits: 2

Formatter
At the core of Java’s support for creating formatted output is the Formatter class. It provides format conversions that let you display numbers, strings, and time and date in virtually any format you like. It operates in a manner similar to the C/C++ printf() function, which means that if you are familiar with C/C++, then learning to use Formatter will be very easy. It also further streamlines the conversion of C/C++ code to Java. If you are not familiar with C/C++, it is still quite easy to format data.

NOTE Although Java’s Formatter class operates in a manner very similar to the C/C++ printf() function, there are some differences, and some new features. Therefore, if you have a C/C++ background, a careful reading is advised.

The Formatter Constructors
Before you can use Formatter to format output, you must create a Formatter object. In general, Formatter works by converting the binary form of data used by a program into formatted text. It stores the formatted text in a buffer, the contents of which can be obtained by your program whenever they are needed. It is possible to let Formatter supply this buffer automatically, or you can specify the buffer explicitly when a Formatter object is created. It is also possible to have Formatter output its buffer to a file.
The `Formatter` class defines many constructors, which enable you to construct a `Formatter` in a variety of ways. Here is a sampling:

```java
Formatter( )
Formatter(Appendable buf)
Formatter(Appendable buf, Locale loc)
Formatter(String filename)
    throws FileNotFoundException
Formatter(String filename, String charset)
    throws FileNotFoundException, UnsupportedEncodingException
Formatter(File outF)
    throws FileNotFoundException
Formatter(OutputStream outStrm)
```

Here, `buf` specifies a buffer for the formatted output. If `buf` is null, then `Formatter` automatically allocates a `StringBuilder` to hold the formatted output. The `loc` parameter specifies a locale. If no locale is specified, the default locale is used. The `filename` parameter specifies the name of a file that will receive the formatted output. The `charset` parameter specifies the character set. If no character set is specified, then the default character set is used. The `outF` parameter specifies a reference to an open file that will receive output. The `outStrm` parameter specifies a reference to an output stream that will receive output. When using a file, output is also written to the file.

Perhaps the most widely used constructor is the first, which has no parameters. It automatically uses the default locale and allocates a `StringBuilder` to hold the formatted output.

**The Formatter Methods**

`Formatter` defines the methods shown in Table 20-11.
Table 20-11  The Methods Defined by Formatter

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void close( )</td>
<td>Closes the invoking Formatter. This causes any resources used by the object to be released. After a Formatter has been closed, it cannot be reused. An attempt to use a closed Formatter results in a FormatterClosedException.</td>
</tr>
<tr>
<td>void flush( )</td>
<td>Flushes the format buffer. This causes any output currently in the buffer to be written to the destination. This applies mostly to a Formatter tied to a file.</td>
</tr>
<tr>
<td>Formatter format(String fmtString, Object ... args)</td>
<td>Formats the arguments passed via args according to the format specifiers contained in fmtString. Returns the invoking object.</td>
</tr>
<tr>
<td>Formatter format(Locale loc, String fmtString, Object ... args)</td>
<td>Formats the arguments passed via args according to the format specifiers contained in fmtString. The locale specified by loc is used for this format. Returns the invoking object.</td>
</tr>
<tr>
<td>IOException ioException()</td>
<td>If the underlying object that is the destination for output throws an IOException, then this exception is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td>Locale locale( )</td>
<td>Returns the invoking object’s locale.</td>
</tr>
<tr>
<td>Appendable out( )</td>
<td>Returns a reference to the underlying object that is the destination for output.</td>
</tr>
<tr>
<td>String toString( )</td>
<td>Returns a String containing the formatted output.</td>
</tr>
</tbody>
</table>

Formatting Basics

After you have created a Formatter, you can use it to create a formatted string. To do so, use the format() method. The version we will use is shown here:

Formatter format(String fmtString, Object ... args)

The fmtString consists of two types of items. The first type is composed of characters that are simply copied to the output buffer. The second type contains format specifiers that define the way the subsequent arguments are displayed.

In its simplest form, a format specifier begins with a percent sign followed by the format conversion specifier. All format conversion specifiers consist of a single character. For example, the format specifier for floating-point data is %f. In general, there must be the same number of arguments as there are format specifiers, and the format specifiers and the arguments are matched in order from left to right. For
example, consider this fragment:

```java
Formatter fmt = new Formatter();
fmt.format("Formatting %s is easy %d %f", "with Java", 10, 98.6);
```

This sequence creates a **Formatter** that contains the following string:

```
Formatting with Java is easy 10 98.600000
```

In this example, the format specifiers, %s, %d, and %f, are replaced with the arguments that follow the format string. Thus, %s is replaced by “with Java”, %d is replaced by 10, and %f is replaced by 98.6. All other characters are simply used as-is. As you might guess, the format specifier %s specifies a string, and %d specifies an integer value. As mentioned earlier, the %f specifies a floating-point value.

The **format( )** method accepts a wide variety of format specifiers, which are shown in Table 20-12. Notice that many specifiers have both upper- and lowercase forms. When an uppercase specifier is used, then letters are shown in uppercase. Otherwise, the upper- and lowercase specifiers perform the same conversion. It is important to understand that Java type-checks each format specifier against its corresponding argument. If the argument doesn’t match, an **IllegalFormatException** is thrown.
Once you have formatted a string, you can obtain it by calling `toString()`. For example, continuing with the preceding example, the following statement obtains the formatted string contained in `fmt`:

```java
String str = fmt.toString();
```

Of course, if you simply want to display the formatted string, there is no reason to first assign it to a `String` object. When a `Formatter` object is passed to `println()`, for example, its `toString()` method is automatically called.

<table>
<thead>
<tr>
<th>Format Specifier</th>
<th>Conversion Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>%a %A</td>
<td>Floating-point hexadecimal</td>
</tr>
<tr>
<td>%b %B</td>
<td>Boolean</td>
</tr>
<tr>
<td>%c %C</td>
<td>Character</td>
</tr>
<tr>
<td>%d</td>
<td>Decimal integer</td>
</tr>
<tr>
<td>%h %H</td>
<td>Hash code of the argument</td>
</tr>
<tr>
<td>%e %E</td>
<td>Scientific notation</td>
</tr>
<tr>
<td>%f</td>
<td>Decimal floating-point</td>
</tr>
<tr>
<td>%g %G</td>
<td>Uses %e or %f, based on the value being formatted and the precision</td>
</tr>
<tr>
<td>%o</td>
<td>Octal integer</td>
</tr>
<tr>
<td>%n</td>
<td>Inserts a newline character</td>
</tr>
<tr>
<td>%s %S</td>
<td>String</td>
</tr>
<tr>
<td>%t %T</td>
<td>Time and date</td>
</tr>
<tr>
<td>%x %X</td>
<td>Integer hexadecimal</td>
</tr>
<tr>
<td>%%</td>
<td>Inserts a % sign</td>
</tr>
</tbody>
</table>

Table 20-12  The Format Specifiers
Here is a short program that puts together all of the pieces, showing how to create and display a formatted string:

```java
// A very simple example that uses Formatter.
import java.util.*;

class FormatDemo {
    public static void main(String args[]) {
        Formatter fmt = new Formatter();

        fmt.format("Formatting %s is easy %d %f", "with Java", 10, 98.6);

        System.out.println(fmt);
        fmt.close();
    }
}
```

One other point: You can obtain a reference to the underlying output buffer by calling `out()`. It returns a reference to an `Appendable` object.

Now that you know the general mechanism used to create a formatted string, the remainder of this section discusses in detail each conversion. It also describes various options, such as justification, minimum field width, and precision.

### Formatting Strings and Characters

To format an individual character, use `%c`. This causes the matching character argument to be output, unmodified. To format a string, use `%s`.

### Formatting Numbers

To format an integer in decimal format, use `%d`. To format a floating-point value in decimal format, use `%f`. To format a floating-point value in scientific notation, use `%e`. Numbers represented in scientific notation take this general form:

\[ x.ddd \times 10^{\pm y} \]

The `%g` format specifier causes `Formatter` to use either `%f` or `%e`, based on the value being formatted and the precision, which is 6 by default. The following program demonstrates the effect of the `%f` and `%e` format specifiers:
It produces the following output:

1.230000 1.230000e+00
1.230000 1.230000e+00 123.000000 1.230000e+02
1.230000 1.230000e+00 123.000000 1.230000e+02 12300.000000 1.230000e+04

You can display integers in octal or hexadecimal format by using %o and %x, respectively. For example, this fragment:

fmt.format("Hex: %x, Octal: %o", 196, 196);

produces this output:

Hex: c4, Octal: 304

You can display floating-point values in hexadecimal format by using %a. The format produced by %a appears a bit strange at first glance. This is because its representation uses a form similar to scientific notation that consists of a hexadecimal significand and a decimal exponent of powers of 2. Here is the general format:

0x1.sigpexp

Here, sig contains the fractional portion of the significand and exp contains the exponent. The p indicates the start of the exponent. For example, this call:

fmt.format("%a", 512.0);

produces this output:
Formatting Time and Date

One of the more powerful conversion specifiers is %t. It lets you format time and date information. The %t specifier works a bit differently than the others because it requires the use of a suffix to describe the portion and precise format of the time or date desired. The suffixes are shown in Table 20-13. For example, to display minutes, you would use %tM, where M indicates minutes in a two-character field. The argument corresponding to the %t specifier must be of type Calendar, Date, Long, long, or TemporalAccessor.
<table>
<thead>
<tr>
<th>Suffix</th>
<th>Replaced By</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Abbreviated weekday name</td>
</tr>
<tr>
<td>A</td>
<td>Full weekday name</td>
</tr>
<tr>
<td>b</td>
<td>Abbreviated month name</td>
</tr>
<tr>
<td>B</td>
<td>Full month name</td>
</tr>
<tr>
<td>c</td>
<td>Standard date and time string formatted as \textit{day month date hh:mm:ss tzone year}</td>
</tr>
<tr>
<td>C</td>
<td>First two digits of year</td>
</tr>
<tr>
<td>d</td>
<td>Day of month as a decimal (01—31)</td>
</tr>
<tr>
<td>D</td>
<td>month/day/year</td>
</tr>
<tr>
<td>e</td>
<td>Day of month as a decimal (1—31)</td>
</tr>
<tr>
<td>F</td>
<td>year-month-day</td>
</tr>
<tr>
<td>h</td>
<td>Abbreviated month name</td>
</tr>
<tr>
<td>H</td>
<td>Hour (00 to 23)</td>
</tr>
<tr>
<td>I</td>
<td>Hour (01 to 12)</td>
</tr>
<tr>
<td>j</td>
<td>Day of year as a decimal (001 to 366)</td>
</tr>
<tr>
<td>k</td>
<td>Hour (0 to 23)</td>
</tr>
<tr>
<td>l</td>
<td>Hour (1 to 12)</td>
</tr>
<tr>
<td>L</td>
<td>Millisecond (000 to 999)</td>
</tr>
<tr>
<td>m</td>
<td>Month as decimal (01 to 13)</td>
</tr>
<tr>
<td>M</td>
<td>Minute as decimal (00 to 59)</td>
</tr>
<tr>
<td>N</td>
<td>Nanosecond (000000000 to 9999999999)</td>
</tr>
<tr>
<td>p</td>
<td>Locale’s equivalent of AM or PM in lowercase</td>
</tr>
<tr>
<td>Q</td>
<td>Milliseconds from 1/1/1970</td>
</tr>
<tr>
<td>r</td>
<td>\textit{hh:mm:ss} (12-hour format)</td>
</tr>
<tr>
<td>R</td>
<td>\textit{hh:mm} (24-hour format)</td>
</tr>
<tr>
<td>S</td>
<td>Seconds (00 to 60)</td>
</tr>
<tr>
<td>s</td>
<td>Seconds from 1/1/1970 UTC</td>
</tr>
</tbody>
</table>
Here is a program that demonstrates several of the formats:

```java
// Formatting time and date.
import java.util.*;

class TimeDateFormat {
    public static void main(String args[]) {
        Formatter fmt = new Formatter();
        Calendar cal = Calendar.getInstance();

        // Display standard 12-hour time format.
        fmt.format("%tr", cal);
        System.out.println(fmt);
        fmt.close();

        // Display complete time and date information.
        fmt = new Formatter();
        fmt.format("%tc", cal);
        System.out.println(fmt);
        fmt.close();

        // Display just hour and minute.
        fmt = new Formatter();
        fmt.format("%tI:%tM", cal, cal);
        System.out.println(fmt);
        fmt.close();

        // Display month by name and number.
        fmt = new Formatter();
        fmt.format("%tB %tB %tM", cal, cal, cal);
        System.out.println(fmt);
        fmt.close();
    }
}
```
Sample output is shown here:

03:15:34 PM
Sun Jan 01 15:15:34 CST 2017
3:15
January Jan 01

The %n and %%% Specifiers

The %n and %%% format specifiers differ from the others in that they do not match an argument. Instead, they are simply escape sequences that insert a character into the output sequence. The %n inserts a newline. The %%% inserts a percent sign. Neither of these characters can be entered directly into the format string. Of course, you can also use the standard escape sequence \n to embed a newline character.

Here is an example that demonstrates the %n and %%% format specifiers:

```java
// Demonstrate the %n and % format specifiers.
import java.util.*;

class FormatDemo3 {
    public static void main(String args[]) {
        Formatter fmt = new Formatter();

        fmt.format("Copying file%nTransfer is %d%%% complete", 88);
        System.out.println(fmt);
        fmt.close();
    }
}
```

It displays the following output:

Copying file
Transfer is 88% complete

Specifying a Minimum Field Width

An integer placed between the % sign and the format conversion code acts as a minimum field-width specifier. This pads the output with spaces to ensure that it reaches a certain minimum length. If the string or number is longer than that minimum, it will still be printed in full. The default padding is done with spaces. If you want to pad with 0’s, place a 0 before the field-width specifier. For example, %05d will pad a number of less than five digits with 0’s so that its total length is five. The field-width specifier can be used with all format specifiers except %n.
The following program demonstrates the minimum field-width specifier by applying it to the \%f conversion:

// Demonstrate a field-width specifier.
import java.util.*;

class FormatDemo4 {
    public static void main(String args[]) {
        Formatter fmt = new Formatter();

        fmt.format("| %f | %n | %12f | %n | %012f |",
                   10.12345, 10.12345, 10.12345);
        System.out.println(fmt);
        fmt.close();
    }
}

This program produces the following output:

| 10.123450 |
| 10.123450 |
| 00010.123450 |

The first line displays the number 10.12345 in its default width. The second line displays that value in a 12-character field. The third line displays the value in a 12-character field, padded with leading zeros.

The minimum field-width modifier is often used to produce tables in which the columns line up. For example, the next program produces a table of squares and cubes for the numbers between 1 and 10:
The output is shown here:

```
1   1   1
2   4   8
3   9   27
4  16   64
5  25  125
6  36  216
7  49  343
8  64  512
9  81  729
10 100 1000
```

**Specifying Precision**

A *precision specifier* can be applied to the `%f`, `%e`, `%g`, and `%s` format specifiers, among others. It follows the minimum field-width specifier (if there is one) and consists of a period followed by an integer. Its exact meaning depends upon the type of data to which it is applied.

When you apply the precision specifier to floating-point data using the `%f` or `%e` specifiers, it determines the number of decimal places displayed. For example, `%10.4f` displays a number at least ten characters wide with four decimal places. When using `%g`, the precision determines the number of significant digits. The default precision is 6.

Applied to strings, the precision specifier specifies the maximum field length. For example, `%5.7s` displays a string of at least five and not exceeding seven characters.
long. If the string is longer than the maximum field width, the end characters will be truncated.

The following program illustrates the precision specifier:

```java
// Demonstrate the precision modifier.
import java.util.*;

class PrecisionDemo {
    public static void main(String args[]) {
        Formatter fmt = new Formatter();

        // Format 4 decimal places.
        fmt.format("%.4f", 123.1234567);
        System.out.println(fmt);
        fmt.close();

        // Format to 2 decimal places in a 16 character field
        fmt = new Formatter();
        fmt.format("%16.2e", 123.1234567);
        System.out.println(fmt);
        fmt.close();

        // Display at most 15 characters in a string.
        fmt = new Formatter();
        fmt.format("%.15s", "Formatting with Java is now easy.");
        System.out.println(fmt);
        fmt.close();
    }
}
```

It produces the following output:

```
123.1235
  1.23e+02
  Formatting with Java is now easy.
```

**Using the Format Flags**

Formatter recognizes a set of format flags that lets you control various aspects of a conversion. All format flags are single characters, and a format flag follows the `%` in a format specification. The flags are shown here:
Not all flags apply to all format specifiers. The following sections explain each in detail.

### Justifying Output

By default, all output is right-justified. That is, if the field width is larger than the data printed, the data will be placed on the right edge of the field. You can force output to be left-justified by placing a minus sign directly after the %. For instance, `%–10.2f` left-justifies a floating-point number with two decimal places in a 10-character field. For example, consider this program:

```java
// Demonstrate left justification.
import java.util.*;

class LeftJustify {
    public static void main(String args[]) {
        Formatter fmt = new Formatter();

        // Right justify by default
        fmt.format("%10.2f", 123.123);
        System.out.println(fmt);
        fmt.close();

        // Now, left justify.
        fmt = new Formatter();
        fmt.format("%-10.2f", 123.123);
        System.out.println(fmt);
        fmt.close();
    }
}
```
It produces the following output:

| 123.12 |
| 123.12 |

As you can see, the second line is left-justified within a 10-character field.

**The Space, +, 0, and ( Flags**

To cause a + sign to be shown before positive numeric values, add the + flag. For example,

```python
fmt.format("%+d", 100);
```

creates this string:

```
+100
```

When creating columns of numbers, it is sometimes useful to output a space before positive values so that positive and negative values line up. To do this, add the space flag. For example,
// Demonstrate the space format specifiers.
import java.util.*;

class FormatDemo5 {
    public static void main(String args[]) {
        Formatter fmt = new Formatter();

        fmt.format("% d", -100);
        System.out.println(fmt);
        fmt.close();

        fmt = new Formatter();
        fmt.format("% d", 100);
        System.out.println(fmt);
        fmt.close();

        fmt = new Formatter();
        fmt.format("% d", -200);
        System.out.println(fmt);
        fmt.close();

        fmt = new Formatter();
        fmt.format("% d", 200);
        System.out.println(fmt);
        fmt.close();
    }
}

The output is shown here:

-100
100
-200
200

Notice that the positive values have a leading space, which causes the digits in the column to line up properly.

To show negative numeric output inside parentheses, rather than with a leading –, use the ( flag. For example,

fmt.format("%(d", -100);

creates this string:

(100)
The 0 flag causes output to be padded with zeros rather than spaces.

**The Comma Flag**

When displaying large numbers, it is often useful to add grouping separators, which in English are commas. For example, the value 1234567 is more easily read when formatted as 1,234,567. To add grouping specifiers, use the comma (,) flag. For example,

```python
fmt.format("%,.2f", 4356783497.34);
```

creates this string:

```
4,356,783,497.34
```

**The # Flag**

The # can be applied to `%o`, `%x`, `%e`, and `%f`. For `%e` and `%f`, the # ensures that there will be a decimal point even if there are no decimal digits. If you precede the `%x` format specifier with a #, the hexadecimal number will be printed with a `0x` prefix. Preceding the `%o` specifier with # causes the number to be printed with a leading zero.

**The Uppercase Option**

As mentioned earlier, several of the format specifiers have uppercase versions that cause the conversion to use uppercase where appropriate. The following table describes the effect.

<table>
<thead>
<tr>
<th>Specifier</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>%A</td>
<td>Causes the hexadecimal digits a through f to be displayed in uppercase as A through F. Also, the prefix 0x is displayed as 0X, and the p will be displayed as P.</td>
</tr>
<tr>
<td>%B</td>
<td>Uppercases the values true and false.</td>
</tr>
<tr>
<td>%E</td>
<td>Causes the e symbol that indicates the exponent to be displayed in uppercase.</td>
</tr>
<tr>
<td>%G</td>
<td>Causes the e symbol that indicates the exponent to be displayed in uppercase.</td>
</tr>
<tr>
<td>%H</td>
<td>Causes the hexadecimal digits a through f to be displayed in uppercase as A through F.</td>
</tr>
<tr>
<td>%S</td>
<td>Uppercases the corresponding string.</td>
</tr>
<tr>
<td>%X</td>
<td>Causes the hexadecimal digits a through f to be displayed in uppercase as A through F. Also, the optional prefix 0x is displayed as 0X, if present.</td>
</tr>
</tbody>
</table>
For example, this call:

def fmt(format, argument):
    return format % argument;

fmt("%X", 250);

creates this string:

    FA

This call:

def fmt(format, argument):
    return format % argument;

fmt("%E", 123.1234);

creates this string:

    1.231234E+02

Using an Argument Index

Formatter includes a very useful feature that lets you specify the argument to which a format specifier applies. Normally, format specifiers and arguments are matched in order, from left to right. That is, the first format specifier matches the first argument, the second format specifier matches the second argument, and so on. However, by using an argument index, you can explicitly control which argument a format specifier matches.

An argument index immediately follows the `%` in a format specifier. It has the following format:

\[ n\$

where \( n \) is the index of the desired argument, beginning with 1. For example, consider this example:

\[
def fmt(format, argument):
    return format % argument;

fmt("%3$d %1$d %2$d", 10, 20, 30);
\]

It produces this string:

    30 10 20

In this example, the first format specifier matches 30, the second matches 10, and the third matches 20. Thus, the arguments are used in an order other than strictly left to right.

One advantage of argument indexes is that they enable you to reuse an argument without having to specify it twice. For example, consider this line:

\[
def fmt(format, argument):
    return format % argument;

fmt("%d in hex is %1$x", 255);
\]
It produces the following string:

    255 in hex is ff

As you can see, the argument 255 is used by both format specifiers.

There is a convenient shorthand called a relative index that enables you to reuse the argument matched by the preceding format specifier. Simply specify < for the argument index. For example, the following call to format() produces the same results as the previous example:

```java
fmt.format("%d in hex is %<x", 255);
```

Relative indexes are especially useful when creating custom time and date formats. Consider the following example:

```java
// Use relative indexes to simplify the
// creation of a custom time and date format.
import java.util.*;

class FormatDemo6 {
    public static void main(String args[]) {
        Formatter fmt = new Formatter();
        Calendar cal = Calendar.getInstance();

        fmt.format("Today is day %te of %<tB, %<tY", cal);
        System.out.println(fmt);
        fmt.close();
    }
}
```

Here is sample output:

    Today is day 1 of January, 2017

Because of relative indexing, the argument cal need only be passed once, rather than three times.

**Closing a Formatter**

In general, you should close a Formatter when you are done using it. Doing so frees any resources that it was using. This is especially important when formatting to a file, but it can be important in other cases, too. As the previous examples have shown, one way to close a Formatter is to explicitly call close(). However, Formatter also implements the AutoCloseable interface. This means that it
supports the \texttt{try-with-resources} statement. Using this approach, the \texttt{Formatter} is automatically closed when it is no longer needed.

The \texttt{try-with-resources} statement is described in Chapter 13, in connection with files, because files are some of the most commonly used resources that must be closed. However, the same basic techniques apply here. For example, here is the first \texttt{Formatter} example reworked to use automatic resource management:

```java
// Use automatic resource management with \texttt{Formatter}.
import java.util.*;

class FormatDemo {
    public static void main(String args[]) {
        try (Formatter fmt = new Formatter()) {
            fmt.format("Formatting %s is easy %d %f", "with Java", 10, 98.6);
            System.out.println(fmt);
        }
    }
}
```

The output is the same as before.

### The Java printf( ) Connection

Although there is nothing technically wrong with using \texttt{Formatter} directly (as the preceding examples have done) when creating output that will be displayed on the console, there is a more convenient alternative: the \texttt{printf()} method. The \texttt{printf()} method automatically uses \texttt{Formatter} to create a formatted string. It then displays that string on \texttt{System.out}, which is the console by default. The \texttt{printf()} method is defined by both \texttt{PrintStream} and \texttt{PrintWriter}. The \texttt{printf()} method is described in Chapter 21.

### Scanner

\texttt{Scanner} is the complement of \texttt{Formatter}. It reads formatted input and converts it into its binary form. \texttt{Scanner} can be used to read input from the console, a file, a string, or any source that implements the \texttt{Readable} interface or \texttt{ReadableByteChannel}. For example, you can use \texttt{Scanner} to read a number from the keyboard and assign its value to a variable. As you will see, given its power,
Scanner is surprisingly easy to use.

The Scanner Constructors

Scanner defines the constructors shown in Table 20-14. In general, a Scanner can be created for a String, an InputStream, a File, or any object that implements the Readable or ReadableByteChannel interfaces. Here are some examples:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanner( File from )</td>
<td>Creates a Scanner that uses the file specified by from as a source for input.</td>
</tr>
<tr>
<td>throws FileNotFoundException</td>
<td></td>
</tr>
<tr>
<td>Scanner( File from, String charset )</td>
<td>Creates a Scanner that uses the file specified by from with the encoding specified by charset as a source for input.</td>
</tr>
<tr>
<td>throws FileNotFoundException</td>
<td></td>
</tr>
<tr>
<td>Scanner( InputStream from )</td>
<td>Creates a Scanner that uses the stream specified by from as a source for input.</td>
</tr>
<tr>
<td>Scanner( InputStream from, String charset )</td>
<td>Creates a Scanner that uses the stream specified by from with the encoding specified by charset as a source for input.</td>
</tr>
<tr>
<td>Scanner( Path from )</td>
<td>Creates a Scanner that uses the file specified by from as a source for input.</td>
</tr>
<tr>
<td>throws IOException</td>
<td></td>
</tr>
<tr>
<td>Scanner( Path from, String charset )</td>
<td>Creates a Scanner that uses the file specified by from with the encoding specified by charset as a source for input.</td>
</tr>
<tr>
<td>throws IOException</td>
<td></td>
</tr>
<tr>
<td>Scanner( Readable from )</td>
<td>Creates a Scanner that uses the Readable object specified by from as a source for input.</td>
</tr>
<tr>
<td>Scanner (ReadableByteChannel from)</td>
<td>Creates a Scanner that uses the ReadableByteChannel specified by from as a source for input.</td>
</tr>
<tr>
<td>Scanner(ReadableByteChannel from, String charset)</td>
<td>Creates a Scanner that uses the ReadableByteChannel specified by from with the encoding specified by charset as a source for input.</td>
</tr>
<tr>
<td>Scanner(String from)</td>
<td>Creates a Scanner that uses the string specified by from as a source for input.</td>
</tr>
</tbody>
</table>

Table 20-14  The Scanner Constructors

The following sequence creates a Scanner that reads the file Test.txt:
FileReader fin = new FileReader("Test.txt");
Scanner src = new Scanner(fin);

This works because FileReader implements the Readable interface. Thus, the call to the constructor resolves to Scanner(Readable).

This next line creates a Scanner that reads from standard input, which is the keyboard by default:

Scanner conin = new Scanner(System.in);

This works because System.in is an object of type InputStream. Thus, the call to the constructor maps to Scanner(InputStream).

The next sequence creates a Scanner that reads from a string.

String instr = "10 99.88 scanning is easy."
Scanner conin = new Scanner(instr);

Scanning Basics

Once you have created a Scanner, it is a simple matter to use it to read formatted input. In general, a Scanner reads tokens from the underlying source that you specified when the Scanner was created. As it relates to Scanner, a token is a portion of input that is delineated by a set of delimiters, which is whitespace by default. A token is read by matching it with a particular regular expression, which defines the format of the data. Although Scanner allows you to define the specific type of expression that its next input operation will match, it includes many predefined patterns, which match the primitive types, such as int and double, and strings. Thus, often you won’t need to specify a pattern to match.

In general, to use Scanner, follow this procedure:

1. Determine if a specific type of input is available by calling one of Scanner’s hasNextX methods, where X is the type of data desired.
2. If input is available, read it by calling one of Scanner’s nextX methods.
3. Repeat the process until input is exhausted.
4. Close the Scanner by calling close().

As the preceding indicates, Scanner defines two sets of methods that enable you to read input. The first are the hasNextX methods, which are shown in Table 20-15. These methods determine if the specified type of input is available. For example, calling hasNextInt() returns true only if the next token to be read is an integer. If the desired data is available, then you read it by calling one of Scanner’s nextX
methods, which are shown in Table 20-16. For example, to read the next integer, call `nextInt()`.

The following sequence shows how to read a list of integers from the keyboard.

```java
nextInt()
```
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boolean hasNext()</td>
<td>Returns true if another token of any type is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>Boolean hasNext(Pattern pattern)</td>
<td>Returns true if a token that matches the pattern passed in pattern is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>Boolean hasNext(String pattern)</td>
<td>Returns true if a token that matches the pattern passed in pattern is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>Boolean hasNextBigDecimal()</td>
<td>Returns true if a value that can be stored in a BigDecimal object is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>Boolean hasNextBigInteger()</td>
<td>Returns true if a value that can be stored in a BigInteger object is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>Boolean hasNextBigInteger(int radix)</td>
<td>Returns true if a value in the specified radix that can be stored in a BigInteger object is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>Boolean hasNextBoolean()</td>
<td>Returns true if a boolean value is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>Boolean hasNextByte()</td>
<td>Returns true if a byte value is available to be read. Returns false otherwise. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>Boolean hasNextByte(int radix)</td>
<td>Returns true if a byte value in the specified radix is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>Boolean hasNextDouble()</td>
<td>Returns true if a double value is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>Boolean hasNextFloat()</td>
<td>Returns true if a float value is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>Boolean hasNextInt()</td>
<td>Returns true if an int value is available to be read. Returns false otherwise. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>Boolean hasNextInt(int radix)</td>
<td>Returns true if an int value in the specified radix is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>Boolean hasNextLine()</td>
<td>Returns true if a line of input is available.</td>
</tr>
<tr>
<td>Boolean hasNextLong()</td>
<td>Returns true if a long value is available to be read. Returns false otherwise. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>Boolean hasNextLong(int radix)</td>
<td>Returns true if a long value in the specified radix is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>Boolean hasNextShort()</td>
<td>Returns true if a short value is available to be read. Returns false otherwise. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>Boolean hasNextShort(int radix)</td>
<td>Returns true if a short value in the specified radix is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>String next()</td>
<td>Returns the next token of any type from the input source.</td>
</tr>
<tr>
<td>String next(Pattern pattern)</td>
<td>Returns the next token that matches the pattern passed in <code>pattern</code> from the input source.</td>
</tr>
<tr>
<td>String next(String pattern)</td>
<td>Returns the next token that matches the pattern passed in <code>pattern</code> from the input source.</td>
</tr>
<tr>
<td>BigDecimal nextBigDecimal()</td>
<td>Returns the next token as a <code>BigDecimal</code> object.</td>
</tr>
<tr>
<td>BigInteger nextBigInteger()</td>
<td>Returns the next token as a <code>BigInteger</code> object. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>BigInteger nextBigInteger(int radix)</td>
<td>Returns the next token (using the specified radix) as a <code>BigInteger</code> object.</td>
</tr>
<tr>
<td>boolean nextBoolean()</td>
<td>Returns the next token as a <code>boolean</code> value.</td>
</tr>
<tr>
<td>byte nextByte()</td>
<td>Returns the next token as a <code>byte</code> value. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>byte nextByte(int radix)</td>
<td>Returns the next token (using the specified radix) as a <code>byte</code> value.</td>
</tr>
<tr>
<td>double nextDouble()</td>
<td>Returns the next token as a <code>double</code> value.</td>
</tr>
<tr>
<td>float nextFloat()</td>
<td>Returns the next token as a <code>float</code> value.</td>
</tr>
<tr>
<td>int nextInt()</td>
<td>Returns the next token as an <code>int</code> value. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>int nextInt(int radix)</td>
<td>Returns the next token (using the specified radix) as an <code>int</code> value.</td>
</tr>
<tr>
<td>String nextLine()</td>
<td>Returns the next line of input as a string.</td>
</tr>
<tr>
<td>long nextLong()</td>
<td>Returns the next token as a <code>long</code> value. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>long nextLong(int radix)</td>
<td>Returns the next token (using the specified radix) as a <code>long</code> value.</td>
</tr>
<tr>
<td>short nextShort()</td>
<td>Returns the next token as a <code>short</code> value. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>short nextShort(int radix)</td>
<td>Returns the next token (using the specified radix) as a <code>short</code> value.</td>
</tr>
</tbody>
</table>
Table 20-16  The Scanner next Methods

Scanner cinin = new Scanner(System.in);
int i;

// Read a list of integers.
while(cinin.hasNextInt()) {
    i = cinin.nextInt();
    // ...
}

The while loop stops as soon as the next token is not an integer. Thus, the loop stops reading integers as soon as a non-integer is encountered in the input stream.

If a next method cannot find the type of data it is looking for, it throws an InputMismatchException. A NoSuchElementException is thrown if no more input is available. For this reason, it is best to first confirm that the desired type of data is available by calling a hasNext method before calling its corresponding next method.

Some Scanner Examples

Scanner makes what could be a tedious task into an easy one. To understand why, let’s look at some examples. The following program averages a list of numbers entered at the keyboard:
The program reads numbers from the keyboard, summing them in the process, until the user enters the string "done". It then stops input and displays the average of the numbers. Here is a sample run:

Enter numbers to average.
1.2
2
3.4
4
done
Average is 2.65
The program reads numbers until it encounters a token that does not represent a valid `double` value. When this occurs, it confirms that the token is the string "done". If it is, the program terminates normally. Otherwise, it displays an error.

Notice that the numbers are read by calling `nextDouble()` . This method reads any number that can be converted into a `double` value, including an integer value, such as 2, and a floating-point value like 3.4. Thus, a number read by `nextDouble()` need not specify a decimal point. This same general principle applies to all `next` methods. They will match and read any data format that can represent the type of value being requested.

One thing that is especially nice about `Scanner` is that the same technique used to read from one source can be used to read from another. For example, here is the preceding program reworked to average a list of numbers contained in a text file:
// Use Scanner to compute an average of the values in a file.
import java.util.*;
import java.io.*;

class AvgFile {
    public static void main(String args[])
        throws IOException {

        int count = 0;
        double sum = 0.0;

        // Write output to a file.
        FileWriter fout = new FileWriter("test.txt");
        fout.write("2 3.4 5 6 7.4 9.1 10.5 done");
        fout.close();

        FileReader fin = new FileReader("Test.txt");
        Scanner src = new Scanner(fin);

        // Read and sum numbers.
        while(src.hasNext()) {
            if(src.hasNextDouble()) {
                sum += src.nextDouble();
                count++;
            } else {
                String str = src.next();
                if(str.equals("done")) break;
                else {
                    System.out.println("File format error.");
                    return;
                }
            }
        }

        src.close();
        System.out.println("Average is " + sum / count);
    }
}
The preceding program illustrates another important feature of Scanner. Notice that the file reader referred to by fin is not closed directly. Rather, it is closed automatically when src calls close(). When you close a Scanner, the Readable associated with it is also closed (if that Readable implements the Closeable interface). Therefore, in this case, the file referred to by fin is automatically closed when src is closed.

Scanner also implements the AutoCloseable interface. This means that it can be managed by a try-with-resources block. As explained in Chapter 13, when try-with-resources is used, the scanner is automatically closed when the block ends. For example, src in the preceding program could have been managed like this:

```java
try (Scanner src = new Scanner(fin))
{
    // Read and sum numbers.
    while(src.hasNext()) {
        if(src.hasNextDouble()) {
            sum += src.nextDouble();
            count++;
        }
        else {
            String str = src.next();
            if(str.equals("done")) break;
            else {
                System.out.println("File format error.");
                return;
            }
        }
    }
}
```

To clearly demonstrate the closing of a Scanner, the following examples will call close() explicitly, but you should feel free to use try-with-resources in your own code when appropriate.

One other point: To keep this and the other examples in this section compact, I/O exceptions are simply thrown out of main(). However, your real-world code will normally handle I/O exceptions itself.

You can use Scanner to read input that contains several different types of data—even if the order of that data is unknown in advance. You must simply check what type of data is available before reading it. For example, consider this program:
// Use Scanner to read various types of data from a file.
import java.util.*;
import java.io.*;

class ScanMixed {
    public static void main(String args[])
        throws IOException {

        int i;
        double d;
        boolean b;
        String str;

        // Write output to a file.
        FileWriter fout = new FileWriter("test.txt");
        fout.write("Testing Scanner 10 12.2 one true two false");
        fout.close();

        FileReader fin = new FileReader("Test.txt");

        Scanner src = new Scanner(fin);

        // Read to end.
        while(src.hasNext()) {
            if(src.hasNextInt()) {
                i = src.nextInt();
                System.out.println("int: " + i);
            }
            else if(src.hasNextDouble()) {
                d = src.nextDouble();
                System.out.println("double: " + d);
            }
            else if(src.hasNextBoolean()) {
                b = src.nextBoolean();
                System.out.println("boolean: " + b);
            }
            else {
                str = src.next();
                System.out.println("String: " + str);
            }
        }

        src.close();
    }
}
Here is the output:

String: Testing
String: Scanner
int: 10
double: 12.2
String: one
boolean: true
String: two
boolean: false

When reading mixed data types, as the preceding program does, you need to be a bit careful about the order in which you call the `next` methods. For example, if the loop reversed the order of the calls to `nextInt()` and `nextDouble()`, both numeric values would have been read as `double`, because `nextDouble()` matches any numeric string that can be represented as a `double`.

**Setting Delimiters**

`Scanner` defines where a token starts and ends based on a set of `delimiters`. The default delimiters are the whitespace characters, and this is the delimiter set that the preceding examples have used. However, it is possible to change the delimiters by calling the `useDelimiter()` method, shown here:

```java
Scanner useDelimiter(String pattern)
Scanner useDelimiter(Pattern pattern)
```

Here, `pattern` is a regular expression that specifies the delimiter set.

Here is the program that reworks the average program shown earlier so that it reads a list of numbers that are separated by commas, and any number of spaces:
// Use Scanner to compute an average a list of
// comma-separated values.
import java.util.*;
import java.io.*;

class SetDelimiters {
    public static void main(String args[])
        throws IOException {

        int count = 0;
double sum = 0.0;

        // Write output to a file.
        FileWriter fout = new FileWriter("test.txt");

        // Now, store values in comma-separated list.
        fout.write("2, 3.4, 5, 6, 7.4, 9.1, 10.5, done");
fout.close();

        FileReader fin = new FileReader("Test.txt");

        Scanner src = new Scanner(fin);
In this version, the numbers written to `test.txt` are separated by commas and spaces. The use of the delimiter pattern ", *, " tells `Scanner` to match a comma and zero or more spaces as delimiters. The output is the same as before.

You can obtain the current delimiter pattern by calling `delimiter()`, shown here:

```java
Pattern delimiter()
```

### Other Scanner Features

`Scanner` defines several other methods in addition to those already discussed. One that is particularly useful in some circumstances is `findInLine()`. Its general forms are shown here:

```java
String findInLine(Pattern pattern)
String findInLine(String pattern)
```

This method searches for the specified pattern within the next line of text. If the pattern is found, the matching token is consumed and returned. Otherwise, `null` is returned. It operates independently of any delimiter set. This method is useful if you
want to locate a specific pattern. For example, the following program locates the Age field in the input string and then displays the age:

```java
// Demonstrate findInLine().
import java.util.*;

class FindInLineDemo {
    public static void main(String args[]) {
        String instr = "Name: Tom Age: 28 ID: 77";

        Scanner conin = new Scanner(instr);

        // Find and display age.
        conin.findInLine("Age:"); // find Age

        if(conin.hasNext())
            System.out.println(conin.nextLine());
        else
            System.out.println("Error!");

        conin.close();
    }
}
```
The output is 28. In the program, `findInLine()` is used to find an occurrence of the pattern "Age". Once found, the next token is read, which is the age.

Related to `findInLine()` is `findWithinHorizon()`. It is shown here:

```java
String findWithinHorizon(Pattern pattern, int count)

String findWithinHorizon(String pattern, int count)
```

This method attempts to find an occurrence of the specified pattern within the next `count` characters. If successful, it returns the matching pattern. Otherwise, it returns `null`. If `count` is zero, then all input is searched until either a match is found or the end of input is encountered.

You can bypass a pattern using `skip()`, shown here:

```java
Scanner skip(Pattern pattern)

Scanner skip(String pattern)
```

If `pattern` is matched, `skip()` simply advances beyond it and returns a reference to the invoking object. If pattern is not found, `skip()` throws `NoSuchElementException`.

Other `Scanner` methods include `radix()`, which returns the default radix used by the `Scanner`; `useRadix()`, which sets the radix; `reset()`, which resets the scanner; and `close()`, which closes the scanner. JDK 9 adds the methods `tokens()`, which returns all tokens in the form of a `Stream<String>`, and `findAll()`, which returns tokens that match the specified pattern in the form of a `Stream<MatchResult>`.

## The ResourceBundle, ListResourceBundle, and PropertyResourceBundle Classes

The `java.util` package includes three classes that aid in the internationalization of your program. The first is the abstract class `ResourceBundle`. It defines methods that enable you to manage a collection of locale-sensitive resources, such as the strings that are used to label the user interface elements in your program. You can define two or more sets of translated strings that support various languages, such as English, German, or Chinese, with each translation set residing in its own bundle. You can then load the bundle appropriate to the current locale and use the strings to construct the program’s user interface.

Resource bundles are identified by their `family name` (also called their `base`
name). To the family name can be added a two-character lowercase language code which specifies the language. In this case, if a requested locale matches the language code, then that version of the resource bundle is used. For example, a resource bundle with a family name of SampleRB could have a German version called SampleRB_de and a Russian version called SampleRB_ru. (Notice that an underscore links the family name to the language code.) Therefore, if the locale is Locale.GERMAN, SampleRB_de will be used.

It is also possible to indicate specific variants of a language that relate to a specific country by specifying a country code after the language code. A country code is a two-character uppercase identifier, such as AU for Australia or IN for India. A country code is also preceded by an underscore when linked to the resource bundle name. Other variations are also supported. A resource bundle that has only the family name is the default bundle. It is used when no language-specific bundles are applicable.

**NOTE** The language codes are defined by ISO standard 639 and the country codes by ISO standard 3166.

The methods defined by ResourceBundle are summarized in Table 20-17. One important point: null keys are not allowed and several of the methods will throw a NullPointerException if null is passed as the key. Notice the nested class ResourceBundle.Control. It is used to control the resource-bundle loading process.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static final void clearCache()</td>
<td>Deletes all resource bundles from the cache that were loaded by the default class loader. Beginning with JDK 9, this method deletes all resource bundles from the cache that were loaded by the module from which this method is called.</td>
</tr>
<tr>
<td>static final void clearCache(ClassLoader ldr)</td>
<td>Deletes all resource bundles from the cache that were loaded by ldr.</td>
</tr>
<tr>
<td>boolean containsKey(String k)</td>
<td>Returns true if k is a key within the invoking resource bundle (or its parent).</td>
</tr>
<tr>
<td>String getBaseBundleName()</td>
<td>Returns the resource bundle's base name if available. Returns null otherwise.</td>
</tr>
<tr>
<td>static final ResourceBundle getBundle(String familyName)</td>
<td>Loads the resource bundle with a family name of familyName using the default locale and the default class loader. Throws MissingResourceException if no resource bundle matching the name is available.</td>
</tr>
<tr>
<td>static ResourceBundle getBundle(String familyName, Module mod)</td>
<td>Loads the resource bundle with a family name of familyName for the module specified by mod. The default locale is used. Throws MissingResourceException if no resource bundle matching the name is available. (Added by JDK 9.)</td>
</tr>
<tr>
<td>static final ResourceBundle getBundle(String familyName, Locale loc)</td>
<td>Loads the resource bundle with a family name of familyName using the specified locale and the default class loader. Throws MissingResourceException if no resource bundle matching the name is available.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>static ResourceBundle getBundle(String <code>familyName</code>, Locale <code>loc</code>, Module <code>mod</code>)</td>
<td>Loads the resource bundle with a family name of <code>familyName</code> using the locale passed in <code>loc</code> for the module specified by <code>mod</code>. Throws <code>MissingResourceException</code> if no resource bundle matching the name is available. (Added by JDK 9.)</td>
</tr>
<tr>
<td>static ResourceBundle getBundle(String <code>familyName</code>, Locale <code>loc</code>, ClassLoader <code>ldr</code>)</td>
<td>Loads the resource bundle with a family name of <code>familyName</code> using the specified locale and the specified class loader. Throws <code>MissingResourceException</code> if no resource bundle matching the name is available.</td>
</tr>
<tr>
<td>static final ResourceBundle getBundle(String <code>familyName</code>, ResourceBundle.Control <code>cntl</code>)</td>
<td>Loads the resource bundle with a family name of <code>familyName</code> using the default locale and the default class loader. The loading process is under the control of <code>cntl</code>. Throws <code>MissingResourceException</code> if no resource bundle matching the name is available.</td>
</tr>
<tr>
<td>static final ResourceBundle getBundle(String <code>familyName</code>, Locale <code>loc</code>, ResourceBundle.Control <code>cntl</code>)</td>
<td>Loads the resource bundle with a family name of <code>familyName</code> using the specified locale and the default class loader. The loading process is under the control of <code>cntl</code>. Throws <code>MissingResourceException</code> if no resource bundle matching the name is available.</td>
</tr>
<tr>
<td>static ResourceBundle getBundle(String <code>familyName</code>, Locale <code>loc</code>, ClassLoader <code>ldr</code>, ResourceBundle.Control <code>cntl</code>)</td>
<td>Loads the resource bundle with a family name of <code>familyName</code> using the specified locale and the specified class loader. The loading process is under the control of <code>cntl</code>. Throws <code>MissingResourceException</code> if no resource bundle matching the name is available.</td>
</tr>
<tr>
<td>abstract Enumeration&lt;String&gt; getKeys()</td>
<td>Returns the resource bundle keys as an enumeration of strings. Any parent's keys are also obtained.</td>
</tr>
<tr>
<td>Locale getLocale()</td>
<td>Returns the locale supported by the resource bundle.</td>
</tr>
<tr>
<td>final Object getObject(String <code>k</code>)</td>
<td>Returns the object associated with the key passed via <code>k</code>. Throws <code>MissingResourceException</code> if <code>k</code> is not in the resource bundle.</td>
</tr>
<tr>
<td>final String getString(String <code>k</code>)</td>
<td>Returns the string associated with the key passed via <code>k</code>. Throws <code>MissingResourceException</code> if <code>k</code> is not in the resource bundle. Throws <code>ClassCastException</code> if the object associated with <code>k</code> is not a string.</td>
</tr>
<tr>
<td>final String[] getStringArray(String <code>k</code>)</td>
<td>Returns the string array associated with the key passed via <code>k</code>. Throws <code>MissingResourceException</code> if <code>k</code> is not in the resource bundle. Throws <code>MissingResourceException</code> if the object associated with <code>k</code> is not a string array.</td>
</tr>
<tr>
<td>protected abstract Object handleGetObject(String <code>k</code>)</td>
<td>Returns the object associated with the key passed via <code>k</code>. Returns <code>null</code> if <code>k</code> is not in the resource bundle.</td>
</tr>
<tr>
<td>protected Set&lt;String&gt; handleKeySet()</td>
<td>Returns the resource bundle keys as a set of strings. No parent's keys are obtained.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td><code>Set&lt;String&gt; keySet()</code></td>
<td>Returns the resource bundle keys as a set of strings. Any parent keys are also obtained.</td>
</tr>
<tr>
<td><code>protected void setParent(ResourceBundle parent)</code></td>
<td>Sets <code>parent</code> as the parent bundle for the resource bundle. When a key is looked up, the parent will be searched if the key is not found in the invoking resource object.</td>
</tr>
</tbody>
</table>

Table 20-17 The Methods Defined by `ResourceBundle`

**NOTE** Notice that JDK 9 adds methods to `ResourceBundle` that support the new modules feature. Furthermore, the addition of modules raises several issues related to the use of resource bundles that are beyond the scope of this discussion. Consult the API documentation for details on how modules affect the use of `ResourceBundle`.

There are two subclasses of `ResourceBundle`. The first is `PropertyResourceBundle`, which manages resources by using property files. `PropertyResourceBundle` adds no methods of its own. The second is the abstract class `ListResourceBundle`, which manages resources in an array of key/value pairs. `ListResourceBundle` adds the method `getContents()`, which all subclasses must implement. It is shown here:

```java
protected abstract Object[ ][ ] getContents()
```

It returns a two-dimensional array that contains key/value pairs that represent resources. The keys must be strings. The values are typically strings, but can be other types of objects.

Here is an example that demonstrates using a resource bundle in an unnamed module. The resource bundle has the family name `SampleRB`. Two resource bundle classes of this family are created by extending `ListResourceBundle`. The first is called `SampleRB`, and it is the default bundle (which uses English). It is shown here:
import java.util.*;
public class SampleRB extends ListResourceBundle {
    protected Object[][] getContents() {
        Object[][] resources = new Object[3][2];

        resources[0][0] = "title";
        resources[0][1] = "My Program";

        resources[1][0] = "StopText";
        resources[1][1] = "Stop";

        resources[2][0] = "StartText";
        resources[2][1] = "Start";

        return resources;
    }
}

The second resource bundle, shown next, is called SampleRB_de. It contains the German translation.

import java.util.*;

// German version.
public class SampleRB_de extends ListResourceBundle {
    protected Object[][] getContents() {
        Object[][] resources = new Object[3][2];

        resources[0][0] = "title";
        resources[0][1] = "Mein Programm";

        resources[1][0] = "StopText";
        resources[1][1] = "Anschlag";

        resources[2][0] = "StartText";
        resources[2][1] = "Anfang";

        return resources;
    }
}

The following program demonstrates these two resource bundles by displaying the string associated with each key for both the default (English) version and the German version:
// Demonstrate a resource bundle.
import java.util.*;

class LRBDemo {
    public static void main(String args[]) {
        // Load the default bundle.
        ResourceBundle rd = ResourceBundle.getBundle("SampleRB");

        System.out.println("English version: ");
        System.out.println("String for Title key : " +
               rd.getString("title"));

        System.out.println("String for StopText key: " +
               rd.getString("StopText"));

        System.out.println("String for StartText key: " +
               rd.getString("StartText");

        // Load the German bundle.
        rd = ResourceBundle.getBundle("SampleRB", Locale.GERMAN);

        System.out.println("\nGerman version: ");
        System.out.println("String for Title key : " +
               rd.getString("title"));

        System.out.println("String for StopText key: " +
               rd.getString("StopText");

        System.out.println("String for StartText key: " +
               rd.getString("StartText");
    }
}

The output from the program is shown here:

English version:
String for Title key : My Program
String for StopText key: Stop
String for StartText key: Start

German version:
String for Title key : Mein Programm
String for StopText key: Anschlag
String for StartText key: Anfang
Miscellaneous Utility Classes and Interfaces

In addition to the classes already discussed, **java.util** includes the following classes:

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base64</td>
<td>Supports Base64 encoding. Encoder and Decoder nested classes are also defined.</td>
</tr>
<tr>
<td>DoubleSummaryStatistics</td>
<td>Supports the compilation of double values. The following statistics are available: average, minimum, maximum, count, and sum.</td>
</tr>
<tr>
<td>EventListenerProxy</td>
<td>Extends the EventListener class to allow additional parameters. See Chapter 24 for a discussion of event listeners.</td>
</tr>
<tr>
<td>EventObject</td>
<td>The superclass for all event classes. Events are discussed in Chapter 24.</td>
</tr>
<tr>
<td>FormattableFlags</td>
<td>Defines formatting flags that are used with the Formattable interface.</td>
</tr>
<tr>
<td>IntSummaryStatistics</td>
<td>Supports the compilation of int values. The following statistics are available: average, minimum, maximum, count, and sum.</td>
</tr>
<tr>
<td>Objects</td>
<td>Various methods that operate on objects.</td>
</tr>
<tr>
<td>PropertyPermission</td>
<td>Manages property permissions.</td>
</tr>
<tr>
<td>ServiceLoader</td>
<td>Provides a means of finding service providers.</td>
</tr>
<tr>
<td>StringJoiner</td>
<td>Supports the concatenation of CharSequences, which may include a separator, a prefix, and a suffix.</td>
</tr>
<tr>
<td>UUID</td>
<td>Encapsulates and manages Universally Unique Identifiers (UUIDs).</td>
</tr>
</tbody>
</table>

The following interfaces are also packaged in **java.util**:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EventListener</td>
<td>Indicates that a class is an event listener. Events are discussed in Chapter 24.</td>
</tr>
<tr>
<td>Formattable</td>
<td>Enables a class to provide custom formatting.</td>
</tr>
</tbody>
</table>

The **java.util Subpackages**

Java defines the following subpackages of **java.util**:

- java.util.concurrent
- java.util.concurrent.atomic
java.util.concurrent, java.util.concurrent.atomic, and java.util.concurrent.locks

The java.util.concurrent package along with its two subpackages, java.util.concurrent.atomic and java.util.concurrent.locks, support concurrent programming. These packages provide a high-performance alternative to using Java’s built-in synchronization features when thread-safe operation is required. Beginning with JDK 7, java.util.concurrent also provides the Fork/Join Framework. These packages are examined in detail in Chapter 28.

java.util.function

The java.util.function package defines several predefined functional interfaces that you can use when creating lambda expressions or method references. They are also widely used throughout the Java API. The functional interfaces defined by java.util.function are shown in Table 20-18 along with a synopsis of their abstract methods. Be aware that some of these interfaces also define default or static methods that supply additional functionality. You will want to explore them fully on your own. (For a discussion of the use of functional interfaces, see Chapter 15.)
<table>
<thead>
<tr>
<th>Interface</th>
<th>Abstract Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>BiConsumer&lt;T, U&gt;</td>
<td>void accept(T tVal, U uVal)</td>
</tr>
<tr>
<td><strong>Description</strong>: Acts on tVal and uVal.</td>
<td></td>
</tr>
<tr>
<td>BiFunction&lt;T, U, R&gt;</td>
<td>R apply(T tVal, U uVal)</td>
</tr>
<tr>
<td><strong>Description</strong>: Acts on tVal and uVal and returns the result.</td>
<td></td>
</tr>
<tr>
<td>BinaryOperator&lt;T&gt;</td>
<td>T apply(T val1, T val2)</td>
</tr>
<tr>
<td><strong>Description</strong>: Acts on two objects of the same type and returns the result, which is also of the same type.</td>
<td></td>
</tr>
<tr>
<td>BiPredicate&lt;T, U&gt;</td>
<td>boolean test(T tVal, U uVal)</td>
</tr>
<tr>
<td><strong>Description</strong>: Returns true if tVal and uVal satisfy the condition defined by test() and false otherwise.</td>
<td></td>
</tr>
<tr>
<td>BooleanSupplier</td>
<td>boolean getAsBoolean()</td>
</tr>
<tr>
<td><strong>Description</strong>: Returns a boolean value.</td>
<td></td>
</tr>
<tr>
<td>Consumer&lt;T&gt;</td>
<td>void accept(T val)</td>
</tr>
<tr>
<td><strong>Description</strong>: Acts on val.</td>
<td></td>
</tr>
<tr>
<td>DoubleBinaryOperator</td>
<td>double applyAsDouble(double val1, double val2)</td>
</tr>
<tr>
<td><strong>Description</strong>: Acts on two double values and returns a double result.</td>
<td></td>
</tr>
<tr>
<td>DoubleConsumer</td>
<td>void accept(double val)</td>
</tr>
<tr>
<td><strong>Description</strong>: Acts on val.</td>
<td></td>
</tr>
<tr>
<td>DoubleFunction&lt;R&gt;</td>
<td>R apply(double val)</td>
</tr>
<tr>
<td><strong>Description</strong>: Acts on a double value and returns the result.</td>
<td></td>
</tr>
<tr>
<td>DoublePredicate</td>
<td>boolean test(double val)</td>
</tr>
<tr>
<td><strong>Description</strong>: Returns true if val satisfies the condition defined by test() and false otherwise.</td>
<td></td>
</tr>
<tr>
<td>DoubleSupplier</td>
<td>double getAsDouble()</td>
</tr>
<tr>
<td><strong>Description</strong>: Returns a double result.</td>
<td></td>
</tr>
<tr>
<td>DoubleToIntFunction</td>
<td>int applyAsInt(double val)</td>
</tr>
<tr>
<td><strong>Description</strong>: Acts on a double value and returns the result as an int.</td>
<td></td>
</tr>
<tr>
<td>DoubleToLongFunction</td>
<td>long applyAsLong(double val)</td>
</tr>
<tr>
<td><strong>Description</strong>: Acts on a double value and returns the result as a long.</td>
<td></td>
</tr>
<tr>
<td>DoubleUnaryOperator</td>
<td>double applyAsDouble(double val)</td>
</tr>
<tr>
<td><strong>Description</strong>: Acts on a double and returns a double result.</td>
<td></td>
</tr>
<tr>
<td>Function&lt;T, R&gt;</td>
<td>R apply(T val)</td>
</tr>
<tr>
<td><strong>Description</strong>: Acts on val and returns the result.</td>
<td></td>
</tr>
<tr>
<td>IntBinaryOperator</td>
<td>int applyAsInt(int val1, int val2)</td>
</tr>
<tr>
<td><strong>Description</strong>: Acts on two int values and returns an int result.</td>
<td></td>
</tr>
<tr>
<td>Class</td>
<td>Method/Expression</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>IntConsumer</td>
<td>int accept(int val)</td>
</tr>
<tr>
<td>IntFunction&lt;R&gt;</td>
<td>R apply(int val)</td>
</tr>
<tr>
<td>IntPredicate</td>
<td>boolean test(int val)</td>
</tr>
<tr>
<td>IntSupplier</td>
<td>int getAsInt()</td>
</tr>
<tr>
<td>IntToDoubleFunction</td>
<td>double applyAsDouble(int val)</td>
</tr>
<tr>
<td>IntToLongFunction</td>
<td>long applyAsLong(int val)</td>
</tr>
<tr>
<td>IntUnaryOperator</td>
<td>int applyAsInt(int val)</td>
</tr>
<tr>
<td>LongBinaryOperator</td>
<td>long applyAsLong(long val1, long val2)</td>
</tr>
<tr>
<td>LongConsumer</td>
<td>void accept(long val)</td>
</tr>
<tr>
<td>LongFunction&lt;R&gt;</td>
<td>R apply(long val)</td>
</tr>
<tr>
<td>LongPredicate</td>
<td>boolean test(long val)</td>
</tr>
<tr>
<td>LongSupplier</td>
<td>long getAsLong()</td>
</tr>
<tr>
<td>LongToDoubleFunction</td>
<td>double applyAsDouble(long val)</td>
</tr>
<tr>
<td>LongToIntFunction</td>
<td>int applyAsInt(long val)</td>
</tr>
<tr>
<td>LongUnaryOperator</td>
<td>long applyAsLong(long val)</td>
</tr>
<tr>
<td>ObjDoubleConsumer&lt;T&gt;</td>
<td>void accept(T val1, double val2)</td>
</tr>
<tr>
<td>Interface Type</td>
<td>Method</td>
</tr>
<tr>
<td>---------------</td>
<td>--------</td>
</tr>
<tr>
<td>ObjIntConsumer&lt;T&gt;</td>
<td>void accept(T val1, int val2)</td>
</tr>
<tr>
<td>ObjLongConsumer&lt;T&gt;</td>
<td>void accept(T val1, long val2)</td>
</tr>
<tr>
<td>Predicate&lt;T&gt;</td>
<td>boolean test(T val)</td>
</tr>
<tr>
<td>Supplier&lt;T&gt;</td>
<td>T get()</td>
</tr>
<tr>
<td>ToDoubleBiFunction&lt;T, U&gt;</td>
<td>double applyAsDouble(T tVal, U uVal)</td>
</tr>
<tr>
<td>ToDoubleFunction&lt;T&gt;</td>
<td>double applyAsDouble(T val)</td>
</tr>
<tr>
<td>ToIntBiFunction&lt;T, U&gt;</td>
<td>int applyAsInt(T tVal, U uVal)</td>
</tr>
<tr>
<td>ToIntFunction&lt;T&gt;</td>
<td>int applyAsInt(T val)</td>
</tr>
<tr>
<td>ToLongBiFunction&lt;T, U&gt;</td>
<td>long applyAsLong(T tVal, U uVal)</td>
</tr>
<tr>
<td>ToLongFunction&lt;T&gt;</td>
<td>long applyAsLong(T val)</td>
</tr>
<tr>
<td>UnaryOperator&lt;T&gt;</td>
<td>T apply(T val)</td>
</tr>
</tbody>
</table>

Table 20-18  Functional Interfaces Defined by java.util.function and Their Abstract Methods

**java.util.jar**

The java.util.jar package provides the ability to read and write Java Archive (JAR) files.

**java.util.logging**
The **java.util.logging** package provides support for program activity logs, which can be used to record program actions, and to help find and debug problems. Beginning with JDK 9, this package is in the **java.logging** module.

### java.util.prefs

The **java.util.prefs** package provides support for user preferences. It is typically used to support program configuration. Beginning with JDK 9, this package is in the **java.prefs** module.

### java.util.regex

The **java.util.regex** package provides support for regular expression handling. It is described in detail in Chapter 30.

### java.util.spi

The **java.util.spi** package provides support for service providers.

### java.util.stream

The **java.util.stream** package contains Java’s stream API. A discussion of the stream API is found in Chapter 29.

### java.util.zip

The **java.util.zip** package provides the ability to read and write files in the popular ZIP and GZIP formats. Both ZIP and GZIP input and output streams are available.
CHAPTER
This chapter explores java.io, which provides support for I/O operations. Chapter 13 presented an overview of Java’s I/O system, including basic techniques for reading and writing files, handling I/O exceptions, and closing a file. Here, we will examine the Java I/O system in greater detail.

As all programmers learn early on, most programs cannot accomplish their goals without accessing external data. Data is retrieved from an input source. The results of a program are sent to an output destination. In Java, these sources or destinations are defined very broadly. For example, a network connection, memory buffer, or disk file can be manipulated by the Java I/O classes. Although physically different, these devices are all handled by the same abstraction: the stream. An I/O stream, as explained in Chapter 13, is a logical entity that either produces or consumes information. An I/O stream is linked to a physical device by the Java I/O system. All I/O streams behave in the same manner, even if the actual physical devices they are linked to differ.

NOTE The stream-based I/O system packaged in java.io and described in this chapter has been part of Java since its original release and is widely used. However, beginning with version 1.4, a second I/O system was added to Java. It is called NIO (which was originally an acronym for New I/O). NIO is packaged in java.nio and its subpackages. The NIO system is described in Chapter 22.

NOTE It is important not to confuse the I/O streams used by the I/O system discussed here with the stream API added by JDK 8. Although conceptually related, they are two different things. Therefore, when the term stream is used in this chapter, it refers to an I/O stream.

The I/O Classes and Interfaces

The I/O classes defined by java.io are listed here:
The `java.io` package also contains two deprecated classes that are not shown in the preceding table: `LineNumberInputStream` and `StringBufferInputStream`. These classes should not be used for new code.

The following interfaces are defined by `java.io`:

<table>
<thead>
<tr>
<th><code>Closeable</code></th>
<th><code>FilenameFilter</code></th>
<th><code>ObjectInputValidation</code></th>
</tr>
</thead>
<tbody>
<tr>
<td><code>DataInput</code></td>
<td><code>Flushable</code></td>
<td><code>ObjectOutput</code></td>
</tr>
<tr>
<td><code>DataOutput</code></td>
<td><code>ObjectInput</code></td>
<td><code>ObjectStreamConstants</code></td>
</tr>
<tr>
<td><code>Externalizable</code></td>
<td><code>ObjectInputFilter</code></td>
<td><code>Serializable</code></td>
</tr>
<tr>
<td><code>FileFilter</code></td>
<td><code>ObjectInputFilter.FilterInfo</code></td>
<td></td>
</tr>
</tbody>
</table>

As you can see, there are many classes and interfaces in the `java.io` package. These include byte and character streams, and object serialization (the storage and retrieval of objects). This chapter examines several commonly used I/O components. We begin our discussion with one of the most distinctive I/O classes: `File`. 
File

Although most of the classes defined by `java.io` operate on streams, the `File` class does not. It deals directly with files and the file system. That is, the `File` class does not specify how information is retrieved from or stored in files; it describes the properties of a file itself. A `File` object is used to obtain or manipulate the information associated with a disk file, such as the permissions, time, date, and directory path, and to navigate subdirectory hierarchies.

NOTE The `Path` interface and `Files` class, which are part of the NIO system, offer a powerful alternative to `File` in many cases. See Chapter 22 for details.

Files are a primary source and destination for data within many programs. Although there are severe restrictions on their use within untrusted code for security reasons, files are still a central resource for storing persistent and shared information. A directory in Java is treated simply as a `File` with one additional property—a list of filenames that can be examined by the `list()` method.

The following constructors can be used to create `File` objects:

```java
File(String directoryPath)
File(String directoryPath, String filename)
File(File dirObj, String filename)
File(URI uriObj)
```

Here, `directoryPath` is the path name of the file; `filename` is the name of the file or subdirectory; `dirObj` is a `File` object that specifies a directory; and `uriObj` is a `URI` object that describes a file.

The following example creates three files: `f1`, `f2`, and `f3`. The first `File` object is constructed with a directory path as the only argument. The second includes two arguments—the path and the filename. The third includes the file path assigned to `f1` and a filename; `f3` refers to the same file as `f2`.

```java
File f1 = new File("/");
File f2 = new File("/","autoexec.bat");
File f3 = new File(f1,"autoexec.bat");
```

NOTE Java does the right thing with path separators between UNIX and Windows conventions. If you use a forward slash (/) on a Windows version of Java, the path will still resolve correctly. Remember, if you are using the Windows convention of a backslash character (\), you will need to use its escape sequence.
The following example demonstrates several of the File methods. It assumes that a directory called java exists off the root directory and that it contains a file called COPYRIGHT.

```java
// Demonstrate File.
import java.io.File;

class FileDemo {
    static void p(String s) {
        System.out.println(s);
    }

    public static void main(String args[]) {
        File f1 = new File("/java COPYRIGHT");

        p("File Name: " + f1.getName());
        p("Path: " + f1.getPath());
        p("Abs Path: " + f1.getAbsolutePath());
        p("Parent: " + f1.getParent());
        p(f1.exists() ? "exists" : "does not exist");
        p(f1.canWrite() ? "is writeable" : "is not writeable");
        p(f1.canRead() ? "is readable" : "is not readable");
        p("is " + (f1.isDirectory() ? "" : "not") + " a directory");
        p(f1.isFile() ? "is normal file" : "might be a named pipe");
        p(f1.isAbsolute() ? "is absolute" : "is not absolute");
        p("File last modified: " + f1.lastModified());
        p("File size: " + f1.length() + " Bytes");
    }
}
```

This program will produce output similar to this:
Most of the File methods are self-explanatory. isFile() and isAbsolute() are not. isFile() returns true if called on a file and false if called on a directory. Also, isFile() returns false for some special files, such as device drivers and named pipes, so this method can be used to make sure the file will behave as a file. The isAbsolute() method returns true if the file has an absolute path and false if its path is relative.

File includes two useful utility methods of special interest. The first is renameTo(), shown here:

    boolean renameTo(File newName)

Here, the filename specified by newName becomes the new name of the invoking File object. It will return true upon success and false if the file cannot be renamed (if you attempt to rename a file so that it uses an existing filename, for example).

The second utility method is delete(), which deletes the disk file represented by the path of the invoking File object. It is shown here:

    boolean delete()

You can also use delete() to delete a directory if the directory is empty. delete() returns true if it deletes the file and false if the file cannot be removed.

Here are some other File methods that you will find helpful:
Methods also exist to mark files as readable, writable, and executable. Because `File` implements the `Comparable` interface, the method `compareTo()` is also supported.

JDK 7 added a method to `File` called `toPath()`, which is shown here:

Path `toPath()` returns a `Path` object that represents the file encapsulated by the invoking `File` object. (In other words, `toPath()` converts a `File` into a `Path`.) `Path` is packaged in `java.nio.file` and is part of NIO. Thus, `toPath()` forms a bridge between the older `File` class and the newer `Path` interface. (See Chapter 22 for a discussion of `Path`.)

**Directories**

A directory is a `File` that contains a list of other files and directories. When you create a `File` object that is a directory, the `isDirectory()` method will return `true`. In this case, you can call `list()` on that object to extract the list of other files and directories inside. It has two forms. The first is shown here:

```
String[ ] list()
```

The list of files is returned in an array of `String` objects.

The program shown here illustrates how to use `list()` to examine the contents of a directory:
// Using directories.
import java.io.File;

class DirList {
    public static void main(String args[]) {
        String dirName = "\java";
        File f1 = new File(dirName);

        if (f1.isDirectory()) {
            System.out.println("Directory of " + dirName);
            String s[] = f1.list();

            for (int i=0; i < s.length; i++) {
                File f = new File(dirName + "/" + s[i]);
                if (f.isDirectory()) {
                    System.out.println(s[i] + " is a directory");
                } else {
                    System.out.println(s[i] + " is a file");
                }
            }
        } else {
            System.out.println(dirName + " is not a directory");
        }
    }
}

Here is sample output from the program. (Of course, the output you see will be different, based on what is in the directory.)

Directory of /java
bin is a directory
lib is a directory
demo is a directory
COPYRIGHT is a file
README is a file
index.html is a file
include is a directory
src.zip is a file
src is a directory

Using FilenameFilter
You will often want to limit the number of files returned by the list() method to include only those files that match a certain filename pattern, or filter. To do this,
you must use a second form of `list()`, shown here:

```java
String[ ] list(FilenameFilter FFObj)
```

In this form, `FFObj` is an object of a class that implements the `FilenameFilter` interface.

`FilenameFilter` defines only a single method, `accept()`, which is called once for each file in a list. Its general form is given here:

```java
boolean accept(File directory, String filename)
```

The `accept()` method returns `true` for files in the directory specified by `directory` that should be included in the list (that is, those that match the `filename` argument) and returns `false` for those files that should be excluded.

The `OnlyExt` class, shown next, implements `FilenameFilter`. It will be used to modify the preceding program to restrict the visibility of the filenames returned by `list()` to files with names that end in the file extension specified when the object is constructed.

```java
import java.io.*;

public class OnlyExt implements FilenameFilter {
    String ext;

    public OnlyExt(String ext) {
        this.ext = "." + ext;
    }

    public boolean accept(File dir, String name) {
        return name.endsWith(ext);
    }
}
```

The modified directory listing program is shown here. Now it will only display files that use the `.html` extension.
The listFiles( ) Alternative

There is a variation to the list( ) method, called listFiles( ), which you might find useful. The signatures for listFiles( ) are shown here:

- File[ ] listFiles( )
- File[ ] listFiles(FilenameFilter FObj)
- File[ ] listFiles(FileFilter FObj)

These methods return the file list as an array of File objects instead of strings. The first method returns all files, and the second returns those files that satisfy the specified FilenameFilter. Aside from returning an array of File objects, these two versions of listFiles( ) work like their equivalent list( ) methods.

The third version of listFiles( ) returns those files with path names that satisfy the specified FileFilter. FileFilter defines only a single method, accept( ), which is called once for each file in a list. Its general form is given here:

    boolean accept(File path)

The accept( ) method returns true for files that should be included in the list (that is, those that match the path argument) and false for those that should be excluded.

Creating Directories

Another two useful File utility methods are mkdir( ) and mkdirs( ). The mkdir( ) method creates a directory, returning true on success and false on failure. Failure can occur for various reasons, such as the path specified in the File object already exists, or the directory cannot be created because the entire path does not exist yet. To create a directory for which no path exists, use the mkdirs( ) method. It creates
both a directory and all the parents of the directory.

The AutoCloseable, Closeable, and Flushable Interfaces

There are three interfaces that are quite important to the stream classes. Two are `Closeable` and `Flushable`. They are defined in `java.io`. The third, `AutoCloseable`, is packaged in `java.lang`.

`AutoCloseable` provides support for the `try`-with-resources statement, which automates the process of closing a resource. (See Chapter 13.) Only objects of classes that implement `AutoCloseable` can be managed by `try`-with-resources. `AutoCloseable` is discussed in Chapter 17, but it is reviewed here for convenience. The `AutoCloseable` interface defines only the `close()` method:

```
void close() throws Exception
```

This method closes the invoking object, releasing any resources that it may hold. It is called automatically at the end of a `try`-with-resources statement, thus eliminating the need to explicitly call `close()`. Because this interface is implemented by all of the I/O classes that open a stream, all such streams can be automatically closed by a `try`-with-resources statement. Automatically closing a stream ensures that it is properly closed when it is no longer needed, thus preventing memory leaks and other problems.

The `Closeable` interface also defines the `close()` method. Objects of a class that implement `Closeable` can be closed. `Closeable` extends `AutoCloseable`. Therefore, any class that implements `Closeable` also implements `AutoCloseable`.

Objects of a class that implements `Flushable` can force buffered output to be written to the stream to which the object is attached. It defines the `flush()` method, shown here:

```
void flush() throws IOException
```

Flushing a stream typically causes buffered output to be physically written to the underlying device. This interface is implemented by all of the I/O classes that write to a stream.

I/O Exceptions

Two exceptions play an important role in I/O handling. The first is `IOException`. As it relates to most of the I/O classes described in this chapter, if an I/O error occurs, an `IOException` is thrown. In many cases, if a file cannot be opened, a `FileNotFoundException` is thrown. `FileNotFoundException` is a subclass of
IOException, so both can be caught with a single catch that catches IOException. For brevity, this is the approach used by most of the sample code in this chapter. However, in your own applications, you might find it useful to catch each exception separately.

Another exception class that is sometimes important when performing I/O is SecurityException. As explained in Chapter 13, in situations in which a security manager is present, several of the file classes will throw a SecurityException if a security violation occurs when attempting to open a file. By default, applications run via java do not use a security manager. For that reason, the I/O examples in this book do not need to watch for a possible SecurityException. However, other applications could generate a SecurityException. In such a case, you will need to handle this exception.

**Two Ways to Close a Stream**

In general, a stream must be closed when it is no longer needed. Failure to do so can lead to memory leaks and resource starvation. The techniques used to close a stream were described in Chapter 13, but because of their importance, they warrant a brief review here before the stream classes are examined.

Beginning with JDK 7, there are two basic ways in which you can close a stream. The first is to explicitly call close() on the stream. This is the traditional approach that has been used since the original release of Java. With this approach, close() is typically called within a finally block. Thus, a simplified skeleton for the traditional approach is shown here:

```java
try {
    // open and access file
} catch (I/O-exception) {
    // ...
} finally {
    // close the file
}
```

This general technique (or variation thereof) is common in code that predates JDK 7.

The second approach to closing a stream is to automate the process by using the try-with-resources statement that was added by JDK 7. The try-with-resources statement is an enhanced form of try that has the following form:
try (resource-specification) {
    // use the resource
}

Typically, resource-specification is a statement or statements that declares and initializes a resource, such as a file or other stream-related resource. It consists of a variable declaration in which the variable is initialized with a reference to the object being managed. When the try block ends, the resource is automatically released. In the case of a file, this means that the file is automatically closed. Thus, there is no need to call close() explicitly. Beginning with JDK 9, it is also possible for the resource specification of the try to consist of a variable that has been declared and initialized earlier in the program. However, that variable must be effectively final, which means that it has not been assigned a new value after being given its initial value.

Here are three key points about the try-with-resources statement:

- Resources managed by try-with-resources must be objects of classes that implement AutoCloseable.
- A resource declared in the try is implicitly final. A resource declared outside the try must be effectively final.
- You can manage more than one resource by separating each declaration by a semicolon.

Also, remember that the scope of a resource declared inside the try is limited to the try-with-resources statement.

The principal advantage of try-with-resources is that the resource (in this case, a stream) is closed automatically when the try block ends. Thus, it is not possible to forget to close the stream, for example. The try-with-resources approach also typically results in shorter, clearer, easier-to-maintain source code.

Because of its advantages, try-with-resources is expected to be used extensively in new code. As a result, most of the code in this chapter (and in this book) will use it. However, because a large amount of older code still exists, it is important for all programmers to also be familiar with the traditional approach to closing a stream. For example, you will quite likely have to work on legacy code that uses the traditional approach or in an environment that uses an older version of Java. There may also be times when the automated approach is not appropriate because of other aspects of your code. For this reason, a few I/O examples in this book will demonstrate the traditional approach so you can see it in action.

One last point: The examples that use try-with-resources must be compiled by a modern version of Java. They won’t work with an older compiler. The examples that
use the traditional approach can be compiled by older versions of Java.

REMEMBER Because try-with-resources streamlines the process of releasing a resource and eliminates the possibility of accidentally forgetting to release a resource, it is the approach recommended for new code when its use is appropriate.

The Stream Classes

Java’s stream-based I/O is built upon four abstract classes: InputStream, OutputStream, Reader, and Writer. These classes were briefly discussed in Chapter 13. They are used to create several concrete stream subclasses. Although your programs perform their I/O operations through concrete subclasses, the top-level classes define the basic functionality common to all stream classes.

InputStream and OutputStream are designed for byte streams. Reader and Writer are designed for character streams. The byte stream classes and the character stream classes form separate hierarchies. In general, you should use the character stream classes when working with characters or strings and use the byte stream classes when working with bytes or other binary objects.

In the remainder of this chapter, both the byte- and character-oriented streams are examined.

The Byte Streams

The byte stream classes provide a rich environment for handling byte-oriented I/O. A byte stream can be used with any type of object, including binary data. This versatility makes byte streams important to many types of programs. Since the byte stream classes are topped by InputStream and OutputStream, our discussion begins with them.

InputStream

InputStream is an abstract class that defines Java’s model of streaming byte input. It implements the AutoCloseable and Closeable interfaces. Most of the methods in this class will throw an IOException when an I/O error occurs. (The exceptions are mark() and markSupported().) Table 21-1 shows the methods in InputStream.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>int available( )</td>
<td>Returns the number of bytes of input currently available for reading.</td>
</tr>
<tr>
<td>void close( )</td>
<td>Closes the input source. Further read attempts will generate an IOException.</td>
</tr>
<tr>
<td>void mark(int numBytes)</td>
<td>Places a mark at the current point in the input stream that will remain valid until numBytes bytes are read.</td>
</tr>
<tr>
<td>boolean markSupported( )</td>
<td>Returns true if mark() / reset() are supported by the invoking stream.</td>
</tr>
<tr>
<td>int read( )</td>
<td>Returns an integer representation of the next available byte of input. -1 is returned when an attempt is made to read at the end of the stream.</td>
</tr>
<tr>
<td>int read(byte buffer[ ])</td>
<td>Attempts to read up to buffer.length bytes into buffer and returns the actual number of bytes that were successfully read. -1 is returned when an attempt is made to read at the end of the stream.</td>
</tr>
<tr>
<td>int read(byte buffer[ ], int offset, int numBytes)</td>
<td>Attempts to read up to numBytes bytes into buffer starting at buffer[offset], returning the number of bytes successfully read. -1 is returned when an attempt is made to read at the end of the stream.</td>
</tr>
<tr>
<td>byte[ ] readAllBytes( )</td>
<td>Beginning at the current position, reads to the end of the stream, returning a byte array that holds the input. (Added by JDK 9.)</td>
</tr>
<tr>
<td>int readNBytes(byte buffer[ ], int offset, int numBytes)</td>
<td>Attempts to read up to numBytes bytes into buffer starting at buffer[offset], returning the number of bytes successfully read. (Added by JDK 9.)</td>
</tr>
<tr>
<td>void reset( )</td>
<td>Resets the input pointer to the previously set mark.</td>
</tr>
<tr>
<td>long skip(long numBytes)</td>
<td>Ignores (that is, skips) numBytes bytes of input, returning the number of bytes actually ignored.</td>
</tr>
<tr>
<td>long.transferTo(OutputStream strm)</td>
<td>Copies the bytes in the invoking stream into strm, returning the number of bytes copied. (Added by JDK 9.)</td>
</tr>
</tbody>
</table>

**Table 21-1** The Methods Defined by **InputStream**

**NOTE** Most of the methods described in Table 21-1 are implemented by the subclasses of **InputStream**. The mark() and reset() methods are exceptions; notice their use, or lack thereof, by each subclass in the discussions that follow.
OutputStream

OutputStream is an abstract class that defines streaming byte output. It implements the AutoCloseable, Closeable, and Flushable interfaces. Most of the methods defined by this class return void and throw an IOException in the case of I/O errors. Table 21-2 shows the methods in OutputStream.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void close()</td>
<td>Closes the output stream. Further write attempts will generate an IOException.</td>
</tr>
<tr>
<td>void flush()</td>
<td>Finalizes the output state so that any buffers are cleared. That is, it flushes the output buffers.</td>
</tr>
<tr>
<td>void write(int b)</td>
<td>Writes a single byte to an output stream. Note that the parameter is an int, which allows you to call write() with an expression without having to cast it back to byte.</td>
</tr>
<tr>
<td>void write(byte buffer[], int offset, int numBytes)</td>
<td>Writes a subrange of numBytes bytes from the array buffer, beginning at buffer[offset].</td>
</tr>
</tbody>
</table>

Table 21-2 The Methods Defined by OutputStream

FileInputStream

The FileInputStream class creates an InputStream that you can use to read bytes from a file. Two commonly used constructors are shown here:

    FileInputStream(String filePath)
    FileInputStream(File fileObj)

Either can throw a FileNotFoundException. Here, filePath is the full path name of a file, and fileObj is a File object that describes the file.

The following example creates two FileInputStreams that use the same disk file and each of the two constructors:

    FileInputStream f0 = new FileInputStream("/autoexec.bat")
    File f = new File("/autoexec.bat");
    FileInputStream f1 = new FileInputStream(f);

    Although the first constructor is probably more commonly used, the second allows you to closely examine the file using the File methods, before attaching it to
an input stream. When a **FileInputStream** is created, it is also opened for reading. **FileInputStream** overrides several of the methods in the abstract class **InputStream**. The **mark( )** and **reset( )** methods are not overridden, and any attempt to use **reset( )** on a **FileInputStream** will generate an **IOException**.

The next example shows how to read a single byte, an array of bytes, and a subrange of an array of bytes. It also illustrates how to use **available( )** to determine the number of bytes remaining and how to use the **skip( )** method to skip over unwanted bytes. The program reads its own source file, which must be in the current directory. Notice that it uses the **try-with-resources** statement to automatically close the file when it is no longer needed.
// Demonstrate FileInputStream.

import java.io.*;

class FileInputStreamDemo {
    public static void main(String args[]) {
        int size;

        // Use try-with-resources to close the stream.
        try (FileInputStream f =
            new FileInputStream("FileInputStreamDemo.java")) {

            System.out.println("Total Available Bytes: " +
                (size = f.available()));

            int n = size/40;
            System.out.println("First " + n +
                " bytes of the file one read() at a time");
            for (int i=0; i < n; i++) {
                System.out.print((char) f.read());
            }

            System.out.println("\nStill Available: " + f.available());

            System.out.println("Reading the next " + n +
                " with one read(b[])");
            byte b[] = new byte[n];
            if (f.read(b) != n) {
                System.err.println("couldn’t read " + n + " bytes.");
            }

            System.out.println(new String(b, 0, n));
            System.out.println("\nStill Available: " + (size = f.available()));
            System.out.println("Skipping half of remaining bytes with skip()");
        }
    }
}
Here is the output produced by this program:

Total Available Bytes: 1714
First 42 bytes of the file one read() at a time
// Demonstrate FileInputStream.

import java.io.*;

class FileInputStreamD

Still Available: 1672
Reading the next 42 with one read(b[])
Still Available: 1630
Skipping half of remaining bytes with skip()
Still Available: 815
Reading 21 into the end of array
Still Available: 794

This somewhat contrived example demonstrates how to read three ways, to skip input, and to inspect the amount of data available on a stream.

NOTE The preceding example and the other examples in this chapter handle any I/O
exceptions that might occur as described in Chapter 13. See Chapter 13 for details and alternatives.

FileOutputStream

FileOutputStream creates an OutputStream that you can use to write bytes to a file. It implements the AutoCloseable, Closeable, and Flushable interfaces. Four of its constructors are shown here:

- FileOutputStream(String filePath)
- FileOutputStream(File fileObj)
- FileOutputStream(String filePath, boolean append)
- FileOutputStream(File fileObj, boolean append)

They can throw a FileNotFoundException. Here, filePath is the full path name of a file, and fileObj is a File object that describes the file. If append is true, the file is opened in append mode.

Creation of a FileOutputStream is not dependent on the file already existing. FileOutputStream will create the file before opening it for output when you create the object. In the case where you attempt to open a read-only file, an exception will be thrown.

The following example creates a sample buffer of bytes by first making a String and then using the getBytes() method to extract the byte array equivalent. It then creates three files. The first, file1.txt, will contain every other byte from the sample. The second, file2.txt, will contain the entire set of bytes. The third and last, file3.txt, will contain only the last quarter.
// Demonstrate FileOutputStream.
// This program uses the traditional approach to closing a file.

import java.io.*;

class FileOutputStreamDemo {
    public static void main(String args[]) {
        String source = "Now is the time for all good men\n" + " to come to the aid of their country\n" + " and pay their due taxes."
        byte buf[] = source.getBytes();
        FileOutputStream f0 = null;
        FileOutputStream f1 = null;
        FileOutputStream f2 = null;

        try {
            f0 = new FileOutputStream("file1.txt");
            f1 = new FileOutputStream("file2.txt");
            f2 = new FileOutputStream("file3.txt");

            // write to first file
            for (int i=0; i < buf.length; i += 2) f0.write(buf[i]);

            // write to second file
            f1.write(buf);

            // write to third file
            f2.write(buf, buf.length-buf.length/4, buf.length/4);
        } catch(IOException e) {
            System.out.println("An I/O Error Occurred");
        } finally {
            try {
                if(f0 != null) f0.close();
            } catch(Exception e) {
                System.out.println("Error Closing file1.txt");
            }
        }
    }
}
Here are the contents of each file after running this program. First, file1.txt:

Now is the time for all good men
   to come to the aid of their country
   and pay their due taxes.

Next, file2.txt:

    Wni h iefralgo e
    t oet h i ftercuty n a hi u ae.

Finally, file3.txt:

    nd pay their due taxes.

As the comment at the top of the program states, the preceding program shows an example that uses the traditional approach to closing a file when it is no longer needed. This approach is required by all versions of Java prior to JDK 7 and is widely used in legacy code. As you can see, quite a bit of rather awkward code is required to explicitly call close() because each call could generate an IOException if the close operation fails. This program can be substantially improved by using the try-with-resources statement. For comparison, here is the revised version. Notice that it is much shorter and streamlined:
ByteArrayInputStream

ByteArrayInputStream is an implementation of an input stream that uses a byte array as the source. This class has two constructors, each of which requires a byte array to provide the data source:

```java
ByteArrayInputStream(byte array[])
ByteArrayInputStream(byte array[], int start, int numBytes)
```

Here, `array` is the input source. The second constructor creates an InputStream from a subset of the byte array that begins with the character at the index specified by `start` and is `numBytes` long.

The close() method has no effect on a ByteArrayInputStream. Therefore, it is
not necessary to call close() on a ByteArrayInputStream, but doing so is not an error.

The following example creates a pair of ByteArrayInputStreams, initializing them with the byte representation of the alphabet:

```java
// Demonstrate ByteArrayInputStream.
import java.io.*;

class ByteArrayInputStreamDemo {
    public static void main(String args[]) {
        String tmp = "abcdefghijklmnopqrstuvwxyz";
        byte b[] = tmp.getBytes();

        ByteArrayInputStream input1 = new ByteArrayInputStream(b);
        ByteArrayInputStream input2 = new ByteArrayInputStream(b, 0, 3);
    }
}
```

The input1 object contains the entire lowercase alphabet, whereas input2 contains only the first three letters.

A ByteArrayInputStream implements both mark() and reset(). However, if mark() has not been called, then reset() sets the stream pointer to the start of the stream—which, in this case, is the start of the byte array passed to the constructor. The next example shows how to use the reset() method to read the same input twice. In this case, the program reads and prints the letters "abc" once in lowercase and then again in uppercase.
import java.io.*;

class ByteArrayOutputStreamReset {
    public static void main(String args[]) {
        String tmp = "abc";
        byte b[] = tmp.getBytes();
        ByteArrayOutputStream in = new ByteArrayOutputStream(b);

        for (int i=0; i<2; i++) {
            int c;
            while ((c = in.read()) != -1) {
                if (i == 0) {
                    System.out.print((char) c);
                } else {
                    System.out.print(Character.toUpperCase((char) c));
                }
            }
            System.out.println();
            in.reset();
        }
    }
}

This example first reads each character from the stream and prints it as-is in lowercase. It then resets the stream and begins reading again, this time converting each character to uppercase before printing. Here's the output:

    abc
    ABC

ByteArrayOutputStream

ByteArrayOutputStream is an implementation of an output stream that uses a byte array as the destination. ByteArrayOutputStream has two constructors, shown here:

    ByteArrayOutputStream()
    ByteArrayOutputStream(int numBytes)

In the first form, a buffer of 32 bytes is created. In the second, a buffer is created with a size equal to that specified by numBytes. The buffer is held in the protected buf field of ByteArrayOutputStream. The buffer size will be increased automatically, if needed. The number of bytes held by the buffer is contained in the protected count field of ByteArrayOutputStream.

    The close() method has no effect on a ByteArrayOutputStream. Therefore, it is
not necessary to call close() on a ByteArrayOutputStream, but doing so is not an error.

The following example demonstrates ByteArrayOutputStream:

// Demonstrate ByteArrayOutputStream.

import java.io.*;

class ByteArrayOutputStreamDemo {
    public static void main(String args[]) {
        ByteArrayOutputStream f = new ByteArrayOutputStream();
        String s = "This should end up in the array";
        byte buf[] = s.getBytes();

        try {
            f.write(buf);
        } catch (IOException e) {
            System.out.println("Error Writing to Buffer");
            return;
        }

        System.out.println("Buffer as a string");
        System.out.println(f.toString());
        System.out.println("Into array");
        byte b[] = f.toByteArray();
        for (int i=0; i<b.length; i++) System.out.print((char) b[i]);
When you run the program, you will create the following output. Notice how after the call to `reset()`, the three X’s end up at the beginning.

```
Buffer as a string
This should end up in the array
Into array
This should end up in the array
To an OutputStream()
Doing a reset
XXX
```

This example uses the `writeTo()` convenience method to write the contents of `f` to `test.txt`. Examining the contents of the `test.txt` file created in the preceding example shows the result we expected:

```
This should end up in the array
```

### Filtered Byte Streams

Filtered streams are simply wrappers around underlying input or output streams that transparently provide some extended level of functionality. These streams are typically accessed by methods that are expecting a generic stream, which is a superclass of the filtered streams. Typical extensions are buffering, character
translation, and raw data translation. The filtered byte streams are `FilterInputStream` and `FilterOutputStream`. Their constructors are shown here:

```java
FilterOutputStream(OutputStream os)
FilterInputStream(InputStream is)
```

The methods provided in these classes are identical to those in `InputStream` and `OutputStream`.

### Buffered Byte Streams

For the byte-oriented streams, a *buffered stream* extends a filtered stream class by attaching a memory buffer to the I/O stream. This buffer allows Java to do I/O operations on more than a byte at a time, thereby improving performance. Because the buffer is available, skipping, marking, and resetting of the stream become possible. The buffered byte stream classes are `BufferedInputStream` and `BufferedOutputStream`. `PushbackInputStream` also implements a buffered stream.

#### BufferedInputStream

Buffering I/O is a very common performance optimization. Java’s `BufferedInputStream` class allows you to "wrap" any `InputStream` into a buffered stream to improve performance.

`BufferedInputStream` has two constructors:

```java
BufferedInputStream(InputStream inputStream)
BufferedInputStream(InputStream inputStream, int bufSize)
```

The first form creates a buffered stream using a default buffer size. In the second, the size of the buffer is passed in `bufSize`. Use of sizes that are multiples of a memory page, a disk block, and so on, can have a significant positive impact on performance. This is, however, implementation-dependent. An optimal buffer size is generally dependent on the host operating system, the amount of memory available, and how the machine is configured. To make good use of buffering doesn’t necessarily require quite this degree of sophistication. A good guess for a size is around 8,192 bytes, and attaching even a rather small buffer to an I/O stream is always a good idea. That way, the low-level system can read blocks of data from the disk or network and store the results in your buffer. Thus, even if you are reading the data a byte at a time out of the `InputStream`, you will be manipulating fast memory most of the time.

Buffering an input stream also provides the foundation required to support moving backward in the stream of the available buffer. Beyond the `read()` and `skip()`
methods implemented in any InputStream, BufferedInputStream also supports the mark() and reset() methods. This support is reflected by BufferedInputStream.markSupported() returning true.

The following example contrives a situation where we can use mark() to remember where we are in an input stream and later use reset() to get back there. This example is parsing a stream for the HTML entity reference for the copyright symbol. Such a reference begins with an ampersand (&) and ends with a semicolon (;) without any intervening whitespace. The sample input has two ampersands to show the case where the reset() happens and where it does not.
// Use buffered input.

import java.io.*;

class BufferedInputStreamDemo {
    public static void main(String args[]) {
        String s = "This is a \&copy; copyright symbol " +
            "but this is &copy; not.\n";
        byte buf[] = s.getBytes();

        ByteArrayInputStream in = new ByteArrayInputStream(buf);
        int c;
        boolean marked = false;

        // Use try-with-resources to manage the file.
        try (BufferedInputStream f = new BufferedInputStream(in)) {
            while ((c = f.read()) != -1) {
                switch(c) {
                case '&':
                    if (!marked) {
                        f.mark(32);
                        marked = true;
                    } else {
                        marked = false;
                    }
                    break;
                case ';':
                    if (marked) {
                        marked = false;
                        System.out.print("(c)");
                    } else
                        System.out.print((char) c);
                    break;
                }
case ' ':  
    if (marked) {  
        marked = false;  
        f.reset();  
        System.out.print("&");  
    } else  
        System.out.print((char) c);  
    break;  
    default:  
        if (!marked)  
            System.out.print((char) c);  
        break;  
    }  
}  
}  
}  
catch (IOException e) {  
    System.out.println("I/O Error: " + e);  
}  
}  
}

Notice that this example uses mark(32), which preserves the mark for the next 32 bytes read (which is enough for all entity references). Here is the output produced by this program:

    This is a (c) copyright symbol but this is &copy not.

**BufferedOutputStream**

A **BufferedOutputStream** is similar to any **OutputStream** with the exception that the **flush()** method is used to ensure that data buffers are written to the stream being buffered. Since the point of a **BufferedOutputStream** is to improve performance by reducing the number of times the system actually writes data, you may need to call **flush()** to cause any data that is in the buffer to be immediately written.

Unlike buffered input, buffering output does not provide additional functionality. Buffers for output in Java are there to increase performance. Here are the two available constructors:

BufferedOutputStream(OutputStream **outputStream**)  
BufferedOutputStream(OutputStream **outputStream**, int **bufSize**)  
The first form creates a buffered stream using the default buffer size. In the second form, the size of the buffer is passed in **bufSize**.

**PushbackInputStream**
One of the novel uses of buffering is the implementation of pushback. *Pushback* is used on an input stream to allow a byte to be read and then returned (that is, "pushed back") to the stream. The *PushbackInputStream* class implements this idea. It provides a mechanism to "peek" at what is coming from an input stream without disrupting it.

*PushbackInputStream* has the following constructors:

- `PushbackInputStream(InputStream inputStream)`
- `PushbackInputStream(InputStream inputStream, int numBytes)`

The first form creates a stream object that allows one byte to be returned to the input stream. The second form creates a stream that has a pushback buffer that is `numBytes` long. This allows multiple bytes to be returned to the input stream.

Beyond the familiar methods of *InputStream*, *PushbackInputStream* provides *unread( )*, shown here:

- `void unread(int b)`
- `void unread(byte buffer [])`
- `void unread(byte buffer, int offset, int numBytes)`

The first form pushes back the low-order byte of `b`. This will be the next byte returned by a subsequent call to *read( )* . The second form pushes back the bytes in `buffer`. The third form pushes back `numBytes` bytes beginning at `offset` from `buffer`. An *IOException* will be thrown if there is an attempt to push back a byte when the pushback buffer is full.

Here is an example that shows how a programming language parser might use a *PushbackInputStream* and *unread( )* to deal with the difference between the `==` operator for comparison and the `=` operator for assignment:
// Demonstrate unread().

import java.io.*;

class PushbackInputStreamDemo {
    public static void main(String args[]) {
        String s = "if (a == 4) a = 0;\n";
        byte buf[] = s.getBytes();
        ByteArrayInputStream in = new ByteArrayInputStream(buf);
        int c;

        try (PushbackInputStream f = new PushbackInputStream(in)) {
            while (((c = f.read()) != -1) {  
                switch (c) {
                    case '=':
                        if (((c = f.read()) == '=')
                            System.out.print(".eq.");
                        else {
                            System.out.print("<-"  
                                f.unread(c);
                        }
                    break;
                    default:
                        System.out.print((char) c);
                        break;
                }
            }
        } catch (IOException e) {
            System.out.println("I/O Error: " + e);
        }
    }
}

Here is the output for this example. Notice that == was replaced by ".eq." and = was replaced by "<-".

    if (a .eq. 4) a <- 0;

CAUTION PushbackInputStream has the side effect of invalidating the mark() or reset() methods of the InputStream used to create it. Use markSupported() to check any stream on which you are going to use mark() / reset().
SequenceInputStream

The `SequenceInputStream` class allows you to concatenate multiple `InputStreams`. The construction of a `SequenceInputStream` is different from any other `InputStream`. A `SequenceInputStream` constructor uses either a pair of `InputStreams` or an `Enumeration` of `InputStreams` as its argument:

- `SequenceInputStream(InputStream first, InputStream second)`
- `SequenceInputStream(Enumeration <? extends InputStream> streamEnum)`

Operationally, the class fulfills read requests from the first `InputStream` until it runs out and then switches over to the second one. In the case of an `Enumeration`, it will continue through all of the `InputStreams` until the end of the last one is reached. When the end of each file is reached, its associated stream is closed. Closing the stream created by `SequenceInputStream` causes all unclosed streams to be closed.

Here is a simple example that uses a `SequenceInputStream` to output the contents of two files. For demonstration purposes, this program uses the traditional technique used to close a file. As an exercise, you might want to try changing it to use the `try-with-resources` statement.

```java
// Demonstrate sequenced input.
// This program uses the traditional approach to closing a file.

import java.io.*;
import java.util.*;

class InputStreamEnumerator implements Enumeration<FileInputStream> {
    private Enumeration<String> files;

    public InputStreamEnumerator(Vector<String> files) {
        this.files = files.elements();
    }

    public boolean hasMoreElements() {
        return files.hasMoreElements();
    }

    public FileInputStream nextElement() {
        try {
            return new FileInputStream(files.nextElement().toString());
        }
    }
}
This example creates a Vector and then adds three filenames to it. It passes that vector of names to the InputStreamEnumerator class, which is designed to provide a wrapper on the vector where the elements returned are not the filenames but, rather, open FileInputStreams on those names. The SequenceInputStream opens each file in turn, and this example prints the contents of the files.

Notice in nextElement() that if a file cannot be opened, null is returned. This results in a NullPointerException, which is caught in main().
PrintStream

The PrintStream class provides all of the output capabilities we have been using from the System file handle, System.out, since the beginning of the book. This makes PrintStream one of Java’s most often used classes. It implements the Appendable, AutoCloseable, Closeable, and Flushable interfaces.

PrintStream defines several constructors. The ones shown next have been specified from the start:

PrintStream(OutputStream outputStream)
PrintStream(OutputStream outputStream, boolean autoFlushingOn)
PrintStream(OutputStream outputStream, boolean autoFlushingOn String charSet)

throws UnsupportedEncodingException

Here, outputStream specifies an open OutputStream that will receive output. The autoFlushingOn parameter controls whether the output buffer is automatically flushed every time a newline (\n) character or a byte array is written or when println( ) is called. If autoFlushingOn is true, flushing automatically takes place. If it is false, flushing is not automatic. The first constructor does not automatically flush. You can specify a character encoding by passing its name in charSet.

The next set of constructors gives you an easy way to construct a PrintStream that writes its output to a file:

PrintStream(File outputFile) throws FileNotFoundException
PrintStream(File outputFile, String charSet)

throws FileNotFoundException, UnsupportedEncodingException
PrintStream(String outputFile) throws FileNotFoundException
PrintStream(String outputFile, String charSet) throws
FileNotFoundException,
UnsupportedEncodingException,

These allow a PrintStream to be created from a File object or by specifying the name of a file. In either case, the file is automatically created. Any preexisting file by the same name is destroyed. Once created, the PrintStream object directs all output to the specified file. You can specify a character encoding by passing its name in charSet.

NOTE If a security manager is present, some PrintStream constructors will throw a SecurityException if a security violation occurs.

PrintStream supports the print( ) and println( ) methods for all types, including
Object. If an argument is not a primitive type, the PrintStream methods will call the object’s toString() method and then display the result.

When JDK 5 was released, the printf() method was added to PrintStream. It allows you to specify the precise format of the data to be written. The printf() method formats as described by the Formatter class discussed in Chapter 20. It then writes this data to the invoking stream. Although formatting can be done manually, by using Formatter directly, printf() streamlines the process. It also parallels the C/C++ printf() function, which makes it easy to convert existing C/C++ code into Java. Frankly, printf() was a much welcome addition to the Java API because it greatly simplified the output of formatted data to the console.

The printf() method has the following general forms:

PrintStream printf(String fmtString, Object … args)

PrintStream printf(Locale loc, String fmtString, Object … args)

The first version writes args to standard output in the format specified by fmtString, using the default locale. The second lets you specify a locale. Both return the invoking PrintStream.

In general, printf() works in a manner similar to the format() method specified by Formatter. The fmtString consists of two types of items. The first type is composed of characters that are simply copied to the output buffer. The second type contains format specifiers that define the way the subsequent arguments, specified by args, are displayed. For complete information on formatting output, including a description of the format specifiers, see the Formatter class in Chapter 20.

Because System.out is a PrintStream, you can call printf() on System.out. Thus, printf() can be used in place of println() when writing to the console whenever formatted output is desired. For example, the following program uses printf() to output numeric values in various formats. In the past, such formatting required a bit of work. With the addition of printf(), this is now an easy task.
// Demonstrate printf().

class PrintfDemo {
    public static void main(String args[]) {
        System.out.println("Here are some numeric values " +
                         "in different formats.\n");

        System.out.printf("Various integer formats: ");
        System.out.printf("%d %d %d %05d\n", 3, -3, 3, 3);

        System.out.println();
        System.out.printf("Default floating-point format: %f\n",
                           1234567.123);
        System.out.printf("Floating-point with commas: %,f\n",
                           1234567.123);
        System.out.printf("Negative floating-point default: %,f\n",
                           -1234567.123);
        System.out.printf("Negative floating-point option: %,(f\n",
                           -1234567.123);

        System.out.println();

        System.out.printf("Line up positive and negative values: \n");
        System.out.printf("% ,.2f
% ,.2f\n",
                           1234567.123, -1234567.123);
    }
}

The output is shown here:

Here are some numeric values in different formats.

Various integer formats: 3 (3) +3 00003
Default floating-point format: 1234567.123000
Floating-point with commas: 1,234,567.123000
Negative floating-point default: -1,234,567.123000
Negative floating-point option: (1,234,567.123000)

Line up positive and negative values:
    1,234,567.12
-1,234,567.12

PrintStream also defines the format() method. It has these general forms:
PrintStream format(String fmtString, Object ... args)
PrintStream format(Locale loc, String fmtString, Object … args)

It works exactly like printf().

**DataOutputStream and DataInputStream**

DataOutputStream and DataInputStream enable you to write or read primitive data to or from a stream. They implement the DataOutput and DataInput interfaces, respectively. These interfaces define methods that convert primitive values to or from a sequence of bytes. These streams make it easy to store binary data, such as integers or floating-point values, in a file. Each is examined here.

DataOutputStream extends FilterOutputStream, which extends OutputStream. In addition to implementing DataOutput, DataOutputStream also implements AutoCloseable, Closeable, and Flushable. DataOutputStream defines the following constructor:

DataOutputStream(OutputStream outputStream)

Here, outputStream specifies the output stream to which data will be written. When a DataOutputStream is closed (by calling close()), the underlying stream specified by outputStream is also closed automatically.

DataOutputStream supports all of the methods defined by its superclasses. However, it is the methods defined by the DataOutput interface, which it implements, that make it interesting. DataOutput defines methods that convert values of a primitive type into a byte sequence and then writes it to the underlying stream. Here is a sampling of these methods:

- final void writeDouble(double value) throws IOException
- final void writeBoolean(boolean value) throws IOException
- final void writeInt(int value) throws IOException

Here, value is the value written to the stream.

DataInputStream is the complement of DataOutputStream. It extends FilterInputStream, which extends InputStream. In addition to implementing the DataInput interface, DataInputStream also implements AutoCloseable and Closeable. Here is its only constructor:

DataInputStream(InputStream inputStream)

Here, inputStream specifies the input stream from which data will be read. When a DataInputStream is closed (by calling close()), the underlying stream specified by inputStream is also closed automatically.

Like DataOutputStream, DataInputStream supports all of the methods of its superclasses, but it is the methods defined by the DataInput interface that make it unique. These methods read a sequence of bytes and convert them into values of a
primitive type. Here is a sampling of these methods:

final double readDouble( ) throws IOException
final boolean readBoolean( ) throws IOException
final int readInt( ) throws IOException

The following program demonstrates the use of `DataOutputStream` and `DataInputStream`:

```java
// Demonstrate DataInputStream and DataOutputStream.

import java.io.*;

class DataIODemo {
    public static void main(String args[]) throws IOException {

        // First, write the data.
        try (DataOutputStream dout =
                new DataOutputStream(new FileOutputStream("Test.dat")))
        {
            dout.writeDouble(98.6);
            dout.writeInt(1000);
            dout.writeBoolean(true);
        } catch (FileNotFoundException e) {
            System.out.println("Cannot Open Output File");
            return;
        } catch (IOException e) {
            System.out.println("I/O Error: " + e);
        }
```
RandomAccessFile

RandomAccessFile encapsulates a random-access file. It is not derived from InputStream or OutputStream. Instead, it implements the interfaces DataInput and DataOutput, which define the basic I/O methods. It also implements the AutoCloseable and Closeable interfaces. RandomAccessFile is special because it supports positioning requests—that is, you can position the file pointer within the file. It has these two constructors:

RandomAccessFile(File fileObj, String access)

throws FileNotFoundException

RandomAccessFile(String filename, String access)

throws FileNotFoundException

In the first form, fileObj specifies the file to open as a File object. In the second form, the name of the file is passed in filename. In both cases, access determines what type of file access is permitted. If it is "r", then the file can be read, but not

// Now, read the data back.
try {
    DataInputStream din =
        new DataInputStream(new FileInputStream("Test.dat"));
    
double d = din.readDouble();
    int i = din.readInt();
    boolean b = din.readBoolean();
    
    System.out.println("Here are the values: " +
        d + " " + i + " " + b);
} catch(FileNotFoundException e) {
    System.out.println("Cannot Open Input File");
    return;
}

} catch(IOException e) {
    System.out.println("I/O Error: " + e);
}

The output is shown here:

Here are the values: 98.6 1000 true
written. If it is "rw", then the file is opened in read-write mode. If it is "rws", the file is opened for read-write operations and every change to the file’s data or metadata will be immediately written to the physical device. If it is "rwd", the file is opened for read-write operations and every change to the file’s data will be immediately written to the physical device.

The method `seek()` shown here, is used to set the current position of the file pointer within the file:

```java
void seek(long newPos) throws IOException
```

Here, `newPos` specifies the new position, in bytes, of the file pointer from the beginning of the file. After a call to `seek()`, the next read or write operation will occur at the new file position.

`RandomAccessFile` implements the standard input and output methods, which you can use to read and write to random access files. It also includes some additional methods. One is `setLength()`. It has this signature:

```java
void setLength(long len) throws IOException
```

This method sets the length of the invoking file to that specified by `len`. This method can be used to lengthen or shorten a file. If the file is lengthened, the added portion is undefined.

## The Character Streams

While the byte stream classes provide sufficient functionality to handle any type of I/O operation, they cannot work directly with Unicode characters. Since one of the main purposes of Java is to support the "write once, run anywhere" philosophy, it was necessary to include direct I/O support for characters. In this section, several of the character I/O classes are discussed. As explained earlier, at the top of the character stream hierarchies are the `Reader` and `Writer` abstract classes. We will begin with them.

### Reader

`Reader` is an abstract class that defines Java’s model of streaming character input. It implements the `AutoCloseable`, `Closeable`, and `Readable` interfaces. All of the methods in this class (except for `markSupported()`) will throw an `IOException` on error conditions. Table 21-3 provides a synopsis of the methods in `Reader`. 

---

**Table 21-3**

---
### Table 21-3 The Methods Defined by Reader

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>abstract void close( )</td>
<td>Closes the input source. Further read attempts will generate an IOException.</td>
</tr>
<tr>
<td>void mark(int numChars)</td>
<td>Places a mark at the current point in the input stream that will remain valid until numChars characters are read.</td>
</tr>
<tr>
<td>boolean markSupported( )</td>
<td>Returns true if mark()/reset() are supported on this stream.</td>
</tr>
<tr>
<td>int read( )</td>
<td>Returns an integer representation of the next available character from the invoking input stream. –1 is returned when an attempt is made to read at the end of the stream.</td>
</tr>
<tr>
<td>int read(char buffer[])</td>
<td>Attempts to read up to buffer.length characters into buffer and returns the actual number of characters that were successfully read. –1 is returned when an attempt is made to read at the end of the stream.</td>
</tr>
<tr>
<td>int read(CharBuffer buffer)</td>
<td>Attempts to read characters into buffer and returns the actual number of characters that were successfully read. –1 is returned when an attempt is made to read at the end of the stream.</td>
</tr>
<tr>
<td>abstract int read(char buffer[], int offset, int numChars)</td>
<td>Attempts to read up to numChars characters into buffer starting at buffer[offset], returning the number of characters successfully read. –1 is returned when an attempt is made to read at the end of the stream.</td>
</tr>
<tr>
<td>boolean ready( )</td>
<td>Returns true if the next input request will not wait. Otherwise, it returns false.</td>
</tr>
<tr>
<td>void reset( )</td>
<td>Resets the input pointer to the previously set mark.</td>
</tr>
<tr>
<td>long skip(long numChars)</td>
<td>Skips over numChars characters of input, returning the number of characters actually skipped.</td>
</tr>
</tbody>
</table>

**Writer**

Writer is an abstract class that defines streaming character output. It implements the AutoCloseable, Closeable, Flushable, and Appendable interfaces. All of the methods in this class throw an IOException in the case of errors. Table 21-4 shows a synopsis of the methods in Writer.
Table 21-4  The Methods Defined by `Writer`

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>append(char ch)</code></td>
<td>Appends <code>ch</code> to the end of the invoking output stream. Returns a reference to the invoking stream.</td>
</tr>
<tr>
<td><code>append(CharArray chars)</code></td>
<td>Appends <code>chars</code> to the end of the invoking output stream. Returns a reference to the invoking stream.</td>
</tr>
<tr>
<td><code>append(CharArray chars, int begin, int end)</code></td>
<td>Appends the subrange of <code>chars</code> specified by <code>begin</code> and <code>end−1</code> to the end of the invoking output stream. Returns a reference to the invoking stream.</td>
</tr>
<tr>
<td><code>close()</code></td>
<td>Closes the output stream. Further write attempts will generate an <code>IOException</code>.</td>
</tr>
<tr>
<td><code>flush()</code></td>
<td>Finalizes the output state so that any buffers are cleared. That is, it flushes the output buffers.</td>
</tr>
<tr>
<td><code>write(int ch)</code></td>
<td>Writes a single character to the invoking output stream. Note that the parameter is an <code>int</code>, which allows you to call <code>write</code> with an expression without having to cast it back to <code>char</code>. However, only the low-order 16 bits are written.</td>
</tr>
<tr>
<td><code>write(char buffer[])</code></td>
<td>Writes a complete array of characters to the invoking output stream.</td>
</tr>
<tr>
<td><code>write(char buffer[], int offset, int numChars)</code></td>
<td>Writes a subrange of <code>numChars</code> characters from the array <code>buffer</code>, beginning at <code>buffer[offset]</code> to the invoking output stream.</td>
</tr>
<tr>
<td><code>write(String str)</code></td>
<td>Writes <code>str</code> to the invoking output stream.</td>
</tr>
<tr>
<td><code>write(String str, int offset, int numChars)</code></td>
<td>Writes a subrange of <code>numChars</code> characters from the string <code>str</code>, beginning at the specified <code>offset</code>.</td>
</tr>
</tbody>
</table>

**FileReader**

The **FileReader** class creates a **Reader** that you can use to read the contents of a file. Two commonly used constructors are shown here:

```java
FileReader(String filePath)
FileReader(File fileObj)
```

Either can throw a **FileNotFoundException**. Here, `filePath` is the full path name of a file, and `fileObj` is a **File** object that describes the file.
The following example shows how to read lines from a file and display them on the standard output device. It reads its own source file, which must be in the current directory.

```java
// Demonstrate FileReader.

import java.io.*;

class FileReaderDemo {
    public static void main(String args[]) {
        try (FileReader fr = new FileReader("FileReaderDemo.java")) {
            int c;

            // Read and display the file.
            while((c = fr.read()) != -1) System.out.print((char) c);

        } catch(IOException e) {
            System.out.println("I/O Error: " + e);
        }
    }
}
```

**FileWriter**

FileWriter creates a Writer that you can use to write to a file. Four commonly used constructors are shown here:

- FileWriter(String `filePath`)
- FileWriter(String `filePath`, boolean `append`)
- FileWriter(File `fileObj`)
- FileWriter(File `fileObj`, boolean `append`)

They can all throw an IOException. Here, `filePath` is the full path name of a file, and `fileObj` is a File object that describes the file. If `append` is true, then output is appended to the end of the file.

Creation of a FileWriter is not dependent on the file already existing. FileWriter will create the file before opening it for output when you create the object. In the case where you attempt to open a read-only file, an IOException will be thrown.

The following example is a character stream version of an example shown earlier when FileOutputStream was discussed. This version creates a sample buffer of characters by first making a String and then using the getChars() method to extract
the character array equivalent. It then creates three files. The first, file1.txt, will contain every other character from the sample. The second, file2.txt, will contain the entire set of characters. Finally, the third, file3.txt, will contain only the last quarter.

// Demonstrate FileWriter.

import java.io.*;

class FileWriterDemo {
    public static void main(String args[]) throws IOException {
        String source = "Now is the time for all good men\n" + " to come to the aid of their country\n" + " and pay their due taxes.";
        char[] buffer = new char[source.length()];
        source.getChars(0, source.length(), buffer, 0);

        try (FileWriter f0 = new FileWriter("file1.txt")) {
            FileWriter f1 = new FileWriter("file2.txt");
            FileWriter f2 = new FileWriter("file3.txt")
            {
                // write to first file
                for (int i=0; i < buffer.length; i += 2) {
                    f0.write(buffer[i]);
                }

                // write to second file
                f1.write(buffer);

                // write to third file
                f2.write(buffer, buffer.length-buffer.length/4, buffer.length/4);
            } catch (IOException e) {
                System.out.println("An I/O Error Occurred");
            }
        }
    }
}

CharArrayReader

CharArrayReader is an implementation of an input stream that uses a character array as the source. This class has two constructors, each of which requires a character array to provide the data source:

    CharArrayReader(char array [])
CharArrayReader(char array [], int start, int numChars)
Here, array is the input source. The second constructor creates a Reader from a subset of your character array that begins with the character at the index specified by start and is numChars long.

The close() method implemented by CharArrayReader does not throw any exceptions. This is because it cannot fail.

The following example uses a pair of CharArrayReaders:

```java
// Demonstrate CharArrayReader.

import java.io.*;

public class CharArrayReaderDemo {
    public static void main(String args[]) {
        String tmp = "abcdefgihjklnopqrstuvwxyz";
        int length = tmp.length();
        char c[] = new char[length];
        tmp.getChars(0, length, c, 0);
        int i;

        try (CharArrayReader input1 = new CharArrayReader(c) )
        {
            System.out.println("input1 is:");
            while((i = input1.read()) != -1) {
                System.out.print((char)i);
            }
            System.out.println();
        } catch(IOException e) {
            System.out.println("I/O Error: " + e);
        }

        try (CharArrayReader input2 = new CharArrayReader(c, 0, 5) )
        {
            System.out.println("input2 is:");
            while((i = input2.read()) != -1) {
                System.out.print((char)i);
            }
            System.out.println();
        } catch(IOException e) {
            System.out.println("I/O Error: " + e);
        }
    }
}
```
The **input1** object is constructed using the entire lowercase alphabet, whereas **input2** contains only the first five letters. Here is the output:

```java
input1 is:
abcdefghijklmnopqrstuvwxyz
input2 is:
abcde
```

**CharArrayWriter**

**CharArrayWriter** is an implementation of an output stream that uses an array as the destination. **CharArrayWriter** has two constructors, shown here:

```java
CharArrayWriter()
CharArrayWriter(int numChars)
```

In the first form, a buffer with a default size is created. In the second, a buffer is created with a size equal to that specified by `numChars`. The buffer is held in the **buf** field of **CharArrayWriter**. The buffer size will be increased automatically, if needed. The number of characters held by the buffer is contained in the **count** field of **CharArrayWriter**. Both **buf** and **count** are protected fields.

The **close()** method has no effect on a **CharArrayWriter**.

The following example demonstrates **CharArrayWriter** by reworking the sample program shown earlier for **ByteArrayOutputStream**. It produces the same output as the previous version.
// Demonstrate CharArrayWriter.

import java.io.*;

class CharArrayWriterDemo {
    public static void main(String args[]) throws IOException {
        CharArrayWriter f = new CharArrayWriter();
        String s = "This should end up in the array";
        char buf[] = new char[s.length()];

        s.getChars(0, s.length(), buf, 0);

        try {
            f.write(buf);
        } catch (IOException e) {
            System.out.println("Error Writing to Buffer");
            return;
        }
    }
}
BufferedReader

BufferedReader improves performance by buffering input. It has two constructors:

BufferedReader(Reader inputStream)
BufferedReader(Reader inputStream, int bufSize)

The first form creates a buffered character stream using a default buffer size. In the second, the size of the buffer is passed in bufSize.

Closing a BufferedReader also causes the underlying stream specified by inputStream to be closed.

As is the case with the byte-oriented stream, buffering an input character stream also provides the foundation required to support moving backward in the stream within the available buffer. To support this, BufferedReader implements the mark() and reset() methods, and BufferedReader.markSupported() returns true. JDK 8 added a new method to BufferedReader called lines(). It returns a Stream.
reference to the sequence of lines read by the reader. (Stream is part of the stream API discussed in Chapter 29.)

The following example reworks the BufferedReader example, shown earlier, so that it uses a BufferedReader character stream rather than a buffered byte stream. As before, it uses the mark() and reset() methods to parse a stream for the HTML entity reference for the copyright symbol. Such a reference begins with an ampersand (&) and ends with a semicolon (;) without any intervening whitespace. The sample input has two ampersands to show the case where the reset() happens and where it does not. Output is the same as that shown earlier.

// Use buffered input.

import java.io.*;

class BufferedReaderDemo {
    public static void main(String args[]) throws IOException {
        String s = "This is a &copy; copyright symbol " +
                  "but this is &copy not.\n";
        char buf[] = new char[s.length()];
        s.getChars(0, s.length(), buf, 0);

        CharArrayReader in = new CharArrayReader(buf);
        int c;
        boolean marked = false;

        try (BufferedReader f = new BufferedReader(in)) {

            while ((c = f.read()) != -1) {
                switch(c) {
                case '&':
                    if (!marked) {
                        f.mark(32);
                        marked = true;
                    } else {
                        marked = false;
                    }
                    break;
                case ';':
                    if (marked) {
                        marked = false;
                        System.out.print("(c)"),
                    } else
BufferedWriter

A BufferedWriter is a Writer that buffers output. Using a BufferedWriter can improve performance by reducing the number of times data is actually physically written to the output device.

A BufferedWriter has these two constructors:

BufferedWriter(Writer outputStream)
BufferedWriter(Writer outputStream, int bufSize)

The first form creates a buffered stream using a buffer with a default size. In the second, the size of the buffer is passed in bufSize.

PushbackReader

The PushbackReader class allows one or more characters to be returned to the input stream. This allows you to look ahead in the input stream. Here are its two constructors:

PushbackReader(Reader inputStream)
PushbackReader(Reader inputStream, int bufSize)

The first form creates a buffered stream that allows one character to be pushed back.
In the second, the size of the pushback buffer is passed in \texttt{bufSize}.

Closing a \texttt{PushbackReader} also closes the underlying stream specified by \texttt{inputStream}.

\texttt{PushbackReader} provides \texttt{unread()} which returns one or more characters to the invoking input stream. It has the three forms shown here:

- \texttt{void unread(int \textit{ch}) throws IOException}
- \texttt{void unread(char \textit{buffer} []) throws IOException}
- \texttt{void unread(char \textit{buffer} [], int \textit{offset}, int \textit{numChars}) throws IOException}

The first form pushes back the character passed in \textit{ch}. This will be the next character returned by a subsequent call to \texttt{read()}. The second form returns the characters in \textit{buffer}. The third form pushes back \textit{numChars} characters beginning at \textit{offset} from \textit{buffer}. An \texttt{IOException} will be thrown if there is an attempt to return a character when the pushback buffer is full.

The following program reworks the earlier \texttt{PushbackInputStream} example by replacing \texttt{PushbackInputStream} with \texttt{PushbackReader}. As before, it shows how a programming language parser can use a pushback stream to deal with the difference between the \texttt{==} operator for comparison and the \texttt{=} operator for assignment.
PrintWriter

PrintWriter is essentially a character-oriented version of PrintStream. It implements the Appendable, AutoCloseable, Closeable, and Flushable interfaces. PrintWriter has several constructors. The following have been supplied by PrintWriter from the start:

PrintWriter(OutputStream outputStream)
PrintWriter(OutputStream outputStream, boolean autoFlushingOn)
PrintWriter(Writer outputStream)
PrintWriter(Writer outputStream, boolean autoFlushingOn)

Here, outputStream specifies an open OutputStream that will receive output. The autoFlushingOn parameter controls whether the output buffer is automatically flushed every time println(), printf(), or format() is called. If autoFlushingOn is true, flushing automatically takes place. If false, flushing is not automatic. Constructors that do not specify the autoFlushingOn parameter do not automatically flush.

The next set of constructors gives you an easy way to construct a PrintWriter that writes its output to a file.

PrintWriter(File outputFile) throws FileNotFoundException
PrintWriter(File outputFile, String charSet)
throws FileNotFoundException, UnsupportedEncodingException
PrintWriter(String outputFileName) throws FileNotFoundException
PrintWriter(String outputFileName, String charSet)
throws FileNotFoundException, UnsupportedEncodingException

These allow a PrintWriter to be created from a File object or by specifying the name of a file. In either case, the file is automatically created. Any preexisting file by the same name is destroyed. Once created, the PrintWriter object directs all output to the specified file. You can specify a character encoding by passing its name in charSet.

PrintWriter supports the print() and println() methods for all types, including Object. If an argument is not a primitive type, the PrintWriter methods will call the object’s toString() method and then output the result.

PrintWriter also supports the printf() method. It works the same way it does in the PrintStream class described earlier: It allows you to specify the precise format of the data. Here is how printf() is declared in PrintWriter:

PrintWriter printf(String fmtString, Object … args)
PrintWriter printf(Locale loc, String fmtString, Object … args)

The first version writes args to standard output in the format specified by fmtString, using the default locale. The second lets you specify a locale. Both return the invoking PrintWriter.

The format() method is also supported. It has these general forms:

PrintWriter format(String fmtString, Object … args)
PrintWriter format(Locale loc, String fmtString, Object … args)

It works exactly like printf().
The Console Class

The **Console** class is used to read from and write to the console, if one exists. It implements the **Flushable** interface. **Console** is primarily a convenience class because most of its functionality is available through **System.in** and **System.out**. However, its use can simplify some types of console interactions, especially when reading strings from the console.

**Console** supplies no constructors. Instead, a **Console** object is obtained by calling **System.console()**, which is shown here:

```java
static Console console()
```

If a console is available, then a reference to it is returned. Otherwise, **null** is returned. A console will not be available in all cases. Thus, if **null** is returned, no console I/O is possible.

**Console** defines the methods shown in Table 21-5. Notice that the input methods, such as **readLine()**, throw **IOException** if an input error occurs. **IOException** is a subclass of **Error**. It indicates an I/O failure that is beyond the control of your program. Thus, you will not normally catch an **IOException**. Frankly, if an **IOException** is thrown while accessing the console, it usually means there has been a catastrophic system failure.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void flush()</code></td>
<td>Causes buffered output to be written physically to the console.</td>
</tr>
<tr>
<td><code>Console format(String fmtString, Object...args)</code></td>
<td>Writes <code>args</code> to the console using the format specified by <code>fmtString</code>.</td>
</tr>
<tr>
<td><code>Console printf(String fmtString, Object...args)</code></td>
<td>Writes <code>args</code> to the console using the format specified by <code>fmtString</code>.</td>
</tr>
<tr>
<td><code>Reader reader()</code></td>
<td>Returns a reference to a <code>Reader</code> connected to the console.</td>
</tr>
<tr>
<td><code>String readLine()</code></td>
<td>Reads and returns a string entered at the keyboard. Input stops when the user presses ENTER. If the end of the console input stream has been reached, <code>null</code> is returned. An <code>IOException</code> is thrown on failure.</td>
</tr>
<tr>
<td><code>String readLine(String fmtString, Object...args)</code></td>
<td>Displays a prompting string formatted as specified by <code>fmtString</code> and <code>args</code>, and then reads and returns a string entered at the keyboard. Input stops when the user presses ENTER. If the end of the console input stream has been reached, <code>null</code> is returned. An <code>IOException</code> is thrown on failure.</td>
</tr>
<tr>
<td><code>char[] readPassword()</code></td>
<td>Reads a string entered at the keyboard. Input stops when the user presses ENTER. The string is not displayed. If the end of the console input stream has been reached, <code>null</code> is returned. An <code>IOException</code> is thrown on failure.</td>
</tr>
<tr>
<td><code>char[] readPassword(String fmtString, Object... args)</code></td>
<td>Displays a prompting string formatted as specified by <code>fmtString</code> and <code>args</code>, and then reads a string entered at the keyboard. Input stops when the user presses ENTER. The string is not displayed. If the end of the console input stream has been reached, <code>null</code> is returned. An <code>IOException</code> is thrown on failure.</td>
</tr>
<tr>
<td><code>PrintWriter writer()</code></td>
<td>Returns a reference to a <code>Writer</code> connected to the console.</td>
</tr>
</tbody>
</table>

Table 21-5  The Methods Defined by `Console`

Also notice the `readPassword()` methods. These methods let your application read a password without echoing what is typed. After reading passwords, you should "zero-out" both the array that holds the string entered by the user and the array that holds the password that the string is tested against. This reduces the chance that a malicious program will be able to obtain a password by scanning memory.
Here is an example that demonstrates the **Console** class:

```java
// Demonstrate Console.
import java.io.*;

class ConsoleDemo {
    public static void main(String args[]) {
        String str;
        Console con;

        // Obtain a reference to the console.
        con = System.console();
        // If no console available, exit.
        if(con == null) return;

        // Read a string and then display it.
        str = con.readLine("Enter a string: ");
        con.printf("Here is your string: %s\n", str);
    }
}
```

Here is sample output:

```
Enter a string: This is a test.
Here is your string: This is a test.
```

**Serialization**

*Serialization* is the process of writing the state of an object to a byte stream. This is useful when you want to save the state of your program to a persistent storage area, such as a file. At a later time, you may restore these objects by using the process of deserialization.

Serialization is also needed to implement *Remote Method Invocation (RMI)*. RMI allows a Java object on one machine to invoke a method of a Java object on a different machine. An object may be supplied as an argument to that remote method. The sending machine serializes the object and transmits it. The receiving machine deserializes it. (More information about RMI appears in Chapter 30.)

Assume that an object to be serialized has references to other objects, which, in turn, have references to still more objects. This set of objects and the relationships among them form a directed graph. There may also be circular references within this object graph. That is, object X may contain a reference to object Y, and object Y may contain a reference back to object X. Objects may also contain references to
themselves. The object serialization and deserialization facilities have been designed to work correctly in these scenarios. If you attempt to serialize an object at the top of an object graph, all of the other referenced objects are recursively located and serialized. Similarly, during the process of deserialization, all of these objects and their references are correctly restored.

An overview of the interfaces and classes that support serialization follows.

**Serializable**

Only an object that implements the `Serializable` interface can be saved and restored by the serialization facilities. The `Serializable` interface defines no members. It is simply used to indicate that a class may be serialized. If a class is serializable, all of its subclasses are also serializable.

Variables that are declared as `transient` are not saved by the serialization facilities. Also, `static` variables are not saved.

**Externalizable**

The Java facilities for serialization and deserialization have been designed so that much of the work to save and restore the state of an object occurs automatically. However, there are cases in which the programmer may need to have control over these processes. For example, it may be desirable to use compression or encryption techniques. The `Externalizable` interface is designed for these situations.

The `Externalizable` interface defines these two methods:

```java
void readExternal(ObjectInput inStream) throws IOException, ClassNotFoundException
void writeExternal(ObjectOutput outStream) throws IOException
```

In these methods, `inStream` is the byte stream from which the object is to be read, and `outStream` is the byte stream to which the object is to be written.

**ObjectOutput**

The `ObjectOutput` interface extends the `DataOutput` and `AutoCloseable` interfaces and supports object serialization. It defines the methods shown in Table 21-6. Note especially the `writeObject()` method. This is called to serialize an object. All of these methods will throw an `IOException` on error conditions.
The methods defined by `ObjectOutput`:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void close( )</td>
<td>Closes the invoking stream. Further write attempts will generate an <code>IOException</code>.</td>
</tr>
<tr>
<td>void flush( )</td>
<td>Finalizes the output state so any buffers are cleared. That is, it flushes the output buffers.</td>
</tr>
<tr>
<td>void write(byte buffer[ ])</td>
<td>Writes an array of bytes to the invoking stream.</td>
</tr>
<tr>
<td>void write(byte buffer[ ], int offset, int numBytes)</td>
<td>Writes a subrange of <code>numBytes</code> bytes from the array <code>buffer</code>, beginning at <code>buffer[offset]</code>.</td>
</tr>
<tr>
<td>void write(int b)</td>
<td>Writes a single byte to the invoking stream. The byte written is the low-order byte of <code>b</code>.</td>
</tr>
<tr>
<td>void writeObject(Object obj)</td>
<td>Writes object <code>obj</code> to the invoking stream.</td>
</tr>
</tbody>
</table>

**Table 21-6** The Methods Defined by `ObjectOutput`

**ObjectOutputStream**

The `ObjectOutputStream` class extends the `OutputStream` class and implements the `ObjectOutput` interface. It is responsible for writing objects to a stream. One constructor of this class is shown here:

```java
ObjectOutputStream(OutputStream outStream) throws IOException
```

The argument `outStream` is the output stream to which serialized objects will be written. Closing an `ObjectOutputStream` automatically closes the underlying stream specified by `outStream`.

Several commonly used methods in this class are shown in Table 21-7. They will throw an `IOException` on error conditions. There is also an inner class to `ObjectOutputStream` called `PutField`. It facilitates the writing of persistent fields, and its use is beyond the scope of this book.
ObjectInput

The ObjectInput interface extends the DataInput and AutoCloseable interfaces and defines the methods shown in Table 21-8. It supports object serialization. Note especially the readObject() method. This is called to deserialize an object. All of these methods will throw an IOException on error conditions. The readObject() method can also throw ClassNotFoundException.

Table 21-7  A Sampling of Commonly Used Methods Defined by ObjectOutputStream

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void close( )</td>
<td>Closes the invoking stream. Further write attempts will generate an IOException. The underlying stream is also closed.</td>
</tr>
<tr>
<td>void flush( )</td>
<td>Finalizes the output state so any buffers are cleared. That is, it flushes the output buffers.</td>
</tr>
<tr>
<td>void write(byte buffer[ ])</td>
<td>Writes an array of bytes to the invoking stream.</td>
</tr>
<tr>
<td>void write(byte buffer[ ], int offset, int numBytes)</td>
<td>Writes a subrange of numBytes bytes from the array buffer, beginning at buffer[offset].</td>
</tr>
<tr>
<td>void write(int b)</td>
<td>Writes a single byte to the invoking stream. The byte written is the low-order byte of b.</td>
</tr>
<tr>
<td>void writeBoolean(boolean b)</td>
<td>Writes a boolean to the invoking stream.</td>
</tr>
<tr>
<td>void writeByte(int b)</td>
<td>Writes a byte to the invoking stream. The byte written is the low-order byte of b.</td>
</tr>
<tr>
<td>void writeBytes(String str)</td>
<td>Writes the bytes representing str to the invoking stream.</td>
</tr>
<tr>
<td>void writeChar(int c)</td>
<td>Writes a char to the invoking stream.</td>
</tr>
<tr>
<td>void writeChars(String str)</td>
<td>Writes the characters in str to the invoking stream.</td>
</tr>
<tr>
<td>void writeDouble(double d)</td>
<td>Writes a double to the invoking stream.</td>
</tr>
<tr>
<td>void writeFloat(float f)</td>
<td>Writes a float to the invoking stream.</td>
</tr>
<tr>
<td>void writeInt(int i)</td>
<td>Writes an int to the invoking stream.</td>
</tr>
<tr>
<td>void writeLong(long l)</td>
<td>Writes a long to the invoking stream.</td>
</tr>
<tr>
<td>final void writeObject(Object obj)</td>
<td>Writes obj to the invoking stream.</td>
</tr>
<tr>
<td>void writeShort(int i)</td>
<td>Writes a short to the invoking stream.</td>
</tr>
</tbody>
</table>
Table 21-8  The Methods Defined by ObjectInput

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>int available( )</td>
<td>Returns the number of bytes that are now available in the input buffer.</td>
</tr>
<tr>
<td>void close( )</td>
<td>Closes the invoking stream. Further read attempts will generate an IOException.</td>
</tr>
<tr>
<td>int read( )</td>
<td>Returns an integer representation of the next available byte of input. –1 is returned when an attempt is made to read at the end of the stream.</td>
</tr>
<tr>
<td>int read(byte buffer[ ])</td>
<td>Attempts to read up to buffer.length bytes into buffer, returning the number of bytes that were successfully read. –1 is returned when an attempt is made to read at the end of the stream.</td>
</tr>
<tr>
<td>int read(byte buffer[ ], int offset, int numBytes)</td>
<td>Attempts to read up to numBytes bytes into buffer starting at buffer[offset], returning the number of bytes that were successfully read. –1 is returned when an attempt is made to read at the end of the stream.</td>
</tr>
<tr>
<td>Object readObject( )</td>
<td>Reads an object from the invoking stream.</td>
</tr>
<tr>
<td>long skip(long numBytes)</td>
<td>Ignores (that is, skips) numBytes bytes in the invoking stream, returning the number of bytes actually ignored.</td>
</tr>
</tbody>
</table>

ObjectInputStream

The ObjectInputStream class extends the InputStream class and implements the ObjectInput interface. ObjectInputStream is responsible for reading objects from a stream. One constructor of this class is shown here:

ObjectInputStream(InputStream inStream) throws IOException

The argument inStream is the input stream from which serialized objects should be read. Closing an ObjectInputStream automatically closes the underlying stream specified by inStream.

Several commonly used methods in this class are shown in Table 21-9. They will throw an IOException on error conditions. The readObject( ) method can also throw ClassNotFoundException. There is also an inner class to ObjectInputStream called GetField. It facilitates the reading of persistent fields, and its use is beyond the scope of this book.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>int available( )</td>
<td>Returns the number of bytes that are now available in the input buffer.</td>
</tr>
<tr>
<td>void close( )</td>
<td>Closes the invoking stream. Further read attempts will generate an IOException. The underlying stream is also closed.</td>
</tr>
<tr>
<td>int read( )</td>
<td>Returns an integer representation of the next available byte of input. −1 is returned when an attempt is made to read at the end of the stream.</td>
</tr>
<tr>
<td>int read(byte buffer[], int offset, int numBytes)</td>
<td>Attempts to read up to numBytes bytes into buffer starting at buffer[offset], returning the number of bytes successfully read. −1 is returned when an attempt is made to read at the end of the stream.</td>
</tr>
<tr>
<td>Boolean readBoolean( )</td>
<td>Reads and returns a boolean from the invoking stream.</td>
</tr>
<tr>
<td>byte readByte( )</td>
<td>Reads and returns a byte from the invoking stream.</td>
</tr>
<tr>
<td>char readChar( )</td>
<td>Reads and returns a char from the invoking stream.</td>
</tr>
<tr>
<td>double readDouble( )</td>
<td>Reads and returns a double from the invoking stream.</td>
</tr>
<tr>
<td>float readFloat( )</td>
<td>Reads and returns a float from the invoking stream.</td>
</tr>
<tr>
<td>void readFully(byte buffer[])</td>
<td>Reads buffer.length bytes into buffer. Returns only when all bytes have been read.</td>
</tr>
<tr>
<td>void readFully(byte buffer[], int offset, int numBytes)</td>
<td>Reads numBytes bytes into buffer starting at buffer[offset]. Returns only when numBytes have been read.</td>
</tr>
<tr>
<td>int readInt( )</td>
<td>Reads and returns an int from the invoking stream.</td>
</tr>
<tr>
<td>long readLong( )</td>
<td>Reads and returns a long from the invoking stream.</td>
</tr>
<tr>
<td>final Object readObject( )</td>
<td>Reads and returns an object from the invoking stream.</td>
</tr>
<tr>
<td>short readShort( )</td>
<td>Reads and returns a short from the invoking stream.</td>
</tr>
<tr>
<td>int readUnsignedByte( )</td>
<td>Reads and returns an unsigned byte from the invoking stream.</td>
</tr>
<tr>
<td>int readUnsignedShort( )</td>
<td>Reads and returns an unsigned short from the invoking stream.</td>
</tr>
</tbody>
</table>

**Table 21-9  Commonly Used Methods Defined by ObjectInputStream**

Beginning with JDK 9, `ObjectInputStream` includes the methods `getObjectInputFilter()` and `setObjectInputFilter()`. These support the filtering of object input streams through the use of `ObjectInputFilter`,
ObjectInputFilter.FilterInfo, ObjectInputFilter.Config, and ObjectInputFilter.Status, which were all added by JDK 9. Filtering gives you control over deserialization.

**A Serialization Example**

The following program illustrates how to use object serialization and deserialization. It begins by instantiating an object of class MyClass. This object has three instance variables that are of types String, int, and double. This is the information we want to save and restore.

A FileOutputStream is created that refers to a file named "serial", and an ObjectOutputStream is created for that file stream. The writeObject() method of ObjectOutputStream is then used to serialize our object. The object output stream is flushed and closed.

A FileInputStream is then created that refers to the file named "serial", and an ObjectInputStream is created for that file stream. The readObject() method of ObjectInputStream is then used to deserialize our object. The object input stream is then closed.

Note that MyClass is defined to implement the Serializable interface. If this is not done, a NotSerializableException is thrown. Try experimenting with this program by declaring some of the MyClass instance variables to be transient. That data is then not saved during serialization.
// A serialization demo.

import java.io.*;

public class SerializationDemo {
    public static void main(String args[]) {

        // Object serialization
        try (ObjectOutputStream objOStrm =
             new ObjectOutputStream(new FileOutputStream("serial")))
        {
            MyClass object1 = new MyClass("Hello", -7, 2.7e10);
            System.out.println("object1: "+ object1);

            objOStrm.writeObject(object1);
        }
        catch (IOException e) {
            System.out.println("Exception during serialization: "+ e);
        }

        // Object deserialization
        try (ObjectInputStream objIStrm =
             new ObjectInputStream(new FileInputStream("serial")))
        {
            MyClass object2 = (MyClass)objIStrm.readObject();
            System.out.println("object2: "+ object2);
        }
        catch (Exception e) {
            System.out.println("Exception during deserialization: "+ e);
        }
    }
}
class MyClass implements Serializable {
    String s;
    int i;
    double d;

    public MyClass(String s, int i, double d) {
        this.s = s;
        this.i = i;
        this.d = d;
    }

    public String toString() {
        return "s=" + s + "; i=" + i + "; d=" + d;
    }
}

This program demonstrates that the instance variables of object1 and object2 are identical. The output is shown here:

    object1: s=Hello; i=-7; d=2.7E10
    object2: s=Hello; i=-7; d=2.7E10

    One last point: For classes that you intend to serialize, you will normally want them to define the static, final, long constant serialVersionUID as a private member. Although Java will automatically define this value (as is the case for MyClass in the preceding example), for real world applications, it is far better for you to define this value explicitly.

Stream Benefits

The streaming interface to I/O in Java provides a clean abstraction for a complex and often cumbersome task. The composition of the filtered stream classes allows you to dynamically build the custom streaming interface to suit your data transfer requirements. Java programs written to adhere to the abstract, high-level InputStream, OutputStream, Reader, and Writer classes will function properly in the future even when new and improved concrete stream classes are invented. As you will see in Chapter 23, this model works very well when we switch from a file system–based set of streams to the network and socket streams. Finally, serialization of objects plays an important role in many types of Java programs. Java’s serialization I/O classes provide a portable solution to this sometimes tricky task.
Beginning with version 1.4, Java has provided a second I/O system called NIO (which is short for *New I/O*). It supports a buffer-oriented, channel-based approach to I/O operations. With the release of JDK 7, the NIO system was greatly expanded, providing enhanced support for file-handling and file system features. In fact, so significant were the changes that the term *NIO.2* is often used. Because of the capabilities supported by the NIO file classes, NIO is expected to become an increasingly important approach to file handling. This chapter explores several of the key features of the NIO system.

### The NIO Classes

The NIO classes are contained in the packages shown here. Beginning with JDK 9, all are in the `java.base` module.

<table>
<thead>
<tr>
<th>Package</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>java.nio</td>
<td>Top-level package for the NIO system. Encapsulates various types of buffers that contain data operated upon by the NIO system.</td>
</tr>
<tr>
<td>java.nio.channels</td>
<td>Supports channels, which are essentially open I/O connections.</td>
</tr>
<tr>
<td>java.nio.channels.spi</td>
<td>Supports service providers for channels.</td>
</tr>
<tr>
<td>java.nio.charset</td>
<td>Encapsulates character sets. Also supports encoders and decoders that convert characters to bytes and bytes to characters, respectively.</td>
</tr>
<tr>
<td>java.nio.charset.spi</td>
<td>Supports service providers for character sets.</td>
</tr>
<tr>
<td>java.nio.file</td>
<td>Provides support for files.</td>
</tr>
<tr>
<td>java.nio.file.attribute</td>
<td>Provides support for file attributes.</td>
</tr>
<tr>
<td>java.nio.file.spi</td>
<td>Supports service providers for file systems.</td>
</tr>
</tbody>
</table>

Before we begin, it is important to emphasize that the NIO subsystem does not replace the stream-based I/O classes found in `java.io`, which are discussed in Chapter 21, and good working knowledge of the stream-based I/O in `java.io` is helpful to understanding NIO.
NOTE This chapter assumes that you have read the overview of I/O given in Chapter 13 and the discussion of stream-based I/O supplied in Chapter 21.

NIO Fundamentals

The NIO system is built on two foundational items: buffers and channels. A buffer holds data. A channel represents an open connection to an I/O device, such as a file or a socket. In general, to use the NIO system, you obtain a channel to an I/O device and a buffer to hold data. You then operate on the buffer, inputting or outputting data as needed. The following sections examine buffers and channels in more detail.

Buffers

Buffers are defined in the java.nio package. All buffers are subclasses of the Buffer class, which defines the core functionality common to all buffers: current position, limit, and capacity. The current position is the index within the buffer at which the next read or write operation will take place. The current position is advanced by most read or write operations. The limit is the index value one past the last valid location in the buffer. The capacity is the number of elements that the buffer can hold. Often the limit equals the capacity of the buffer. Buffer also supports mark and reset. Buffer defines several methods, which are shown in Table 22-1.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>abstract Object array()</td>
<td>If the invoking buffer is backed by an array, returns a reference to the array. Otherwise, an <strong>UnsupportedOperationException</strong> is thrown. If the array is read-only, a <strong>ReadOnlyBufferException</strong> is thrown.</td>
</tr>
<tr>
<td>abstract int arrayOffset()</td>
<td>If the invoking buffer is backed by an array, returns the index of the first element. Otherwise, an <strong>UnsupportedOperationException</strong> is thrown. If the array is read-only, a <strong>ReadOnlyBufferException</strong> is thrown.</td>
</tr>
<tr>
<td>final int capacity()</td>
<td>Returns the number of elements that the invoking buffer is capable of holding.</td>
</tr>
<tr>
<td>final Buffer clear()</td>
<td>Clears the invoking buffer and returns a reference to the buffer.</td>
</tr>
<tr>
<td>abstract Buffer duplicate()</td>
<td>Returns a buffer that is identical to the invoking buffer. Thus, both buffers will contain and refer to the same elements. (Added by JDK 9.)</td>
</tr>
<tr>
<td>final Buffer flip()</td>
<td>Sets the invoking buffer’s limit to the current position and resets the current position to 0. Returns a reference to the buffer.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>abstract boolean hasArray()</td>
<td>Returns true if the invoking buffer is backed by a read/write array and false otherwise.</td>
</tr>
<tr>
<td>final boolean hasRemaining()</td>
<td>Returns true if there are elements remaining in the invoking buffer. Returns false otherwise.</td>
</tr>
<tr>
<td>abstract boolean isDirect()</td>
<td>Returns true if the invoking buffer is direct, which means I/O operations act directly upon it. Returns false otherwise.</td>
</tr>
<tr>
<td>abstract boolean isReadOnly()</td>
<td>Returns true if the invoking buffer is read-only. Returns false otherwise.</td>
</tr>
<tr>
<td>final int limit()</td>
<td>Returns the invoking buffer's limit.</td>
</tr>
<tr>
<td>final Buffer limit(int n)</td>
<td>Sets the invoking buffer's limit to n. Returns a reference to the buffer.</td>
</tr>
<tr>
<td>final Buffer mark()</td>
<td>Sets the mark and returns a reference to the invoking buffer.</td>
</tr>
<tr>
<td>final int position()</td>
<td>Returns the current position.</td>
</tr>
<tr>
<td>final Buffer position(int n)</td>
<td>Sets the invoking buffer's current position to n. Returns a reference to the buffer.</td>
</tr>
<tr>
<td>int remaining()</td>
<td>Returns the number of elements available before the limit is reached. In other words, it returns the limit minus the current position.</td>
</tr>
<tr>
<td>final Buffer reset()</td>
<td>Resets the current position of the invoking buffer to the previously set mark. Returns a reference to the buffer.</td>
</tr>
<tr>
<td>final Buffer rewind()</td>
<td>Sets the position of the invoking buffer to 0. Returns a reference to the buffer.</td>
</tr>
<tr>
<td>abstract Buffer slice()</td>
<td>Returns a buffer that consists of the elements in the invoking buffer, beginning at the invoking buffer's current position. Thus, for the slice, both buffers will contain and refer to the same elements. (Added by JDK 9.)</td>
</tr>
</tbody>
</table>

Table 22-1  The Methods Defined by Buffer

From Buffer, the following specific buffer classes are derived, which hold the type of data that their names imply:

<table>
<thead>
<tr>
<th>Buffer Type</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ByteBuffer</td>
<td>CharBuffer</td>
<td>DoubleBuffer</td>
<td>FloatBuffer</td>
<td></td>
</tr>
<tr>
<td>IntBuffer</td>
<td>LongBuffer</td>
<td>MappedByteBuffer</td>
<td>ShortBuffer</td>
<td></td>
</tr>
</tbody>
</table>

MappedByteBuffer is a subclass of ByteBuffer and is used to map a file to a
All of the aforementioned buffers provide various `get()` and `put()` methods, which allow you to get data from a buffer or put data into a buffer. (Of course, if a buffer is read-only, then `put()` operations are not available.) Table 22-2 shows the `get()` and `put()` methods defined by `ByteBuffer`. The other buffer classes have similar methods. All buffer classes also support methods that perform various buffer operations. For example, you can allocate a buffer manually using `allocate()`. You can wrap an array inside a buffer using `wrap()`. You can create a subsequence of a buffer using `slice()`.
Channels are defined in java.nio.channels. A channel represents an open connection to an I/O source or destination. Channels implement the Channel interface. It extends Closeable, and it extends AutoCloseable. By implementing AutoCloseable,

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>abstract byte get()</td>
<td>Returns the byte at the current position.</td>
</tr>
<tr>
<td>ByteBuffer get(byte vals[])</td>
<td>Copies the invoking buffer into the array referred to by vals. Returns a reference to the buffer. If there are not vals.length elements remaining in the buffer, a BufferUnderflowException is thrown.</td>
</tr>
<tr>
<td>ByteBuffer get(byte vals[], int start, int num)</td>
<td>Copies num elements from the invoking buffer into the array referred to by vals, beginning at the index specified by start. Returns a reference to the buffer. If there are not num elements remaining in the buffer, a BufferUnderflowException is thrown.</td>
</tr>
<tr>
<td>abstract byte get(int idx)</td>
<td>Returns the byte at the index specified by idx within the invoking buffer.</td>
</tr>
<tr>
<td>abstract ByteBuffer put(byte b)</td>
<td>Copies b into the invoking buffer at the current position. Returns a reference to the buffer. If the buffer is full, a BufferOverflowException is thrown.</td>
</tr>
<tr>
<td>final ByteBuffer put(byte vals[])</td>
<td>Copies all elements of vals into the invoking buffer, beginning at the current position. Returns a reference to the buffer. If the buffer cannot hold all of the elements, a BufferOverflowException is thrown.</td>
</tr>
<tr>
<td>ByteBuffer put(byte vals[], int start, int num)</td>
<td>Copies num elements from vals, beginning at start, into the invoking buffer. Returns a reference to the buffer. If the buffer cannot hold all of the elements, a BufferOverflowException is thrown.</td>
</tr>
<tr>
<td>ByteBuffer put(ByteBuffer bb)</td>
<td>Copies the elements in bb to the invoking buffer, beginning at the current position. If the buffer cannot hold all of the elements, a BufferOverflowException is thrown. Returns a reference to the buffer.</td>
</tr>
<tr>
<td>abstract ByteBuffer put(int idx, byte b)</td>
<td>Copies b into the invoking buffer at the location specified by idx. Returns a reference to the buffer.</td>
</tr>
</tbody>
</table>

Table 22-2  The get() and put() Methods Defined for ByteBuffer
channels can be managed with a \texttt{try-with-resources} statement. When used in a \texttt{try}-
with-resources block, a channel is closed automatically when it is no longer needed. (See Chapter 13 for a discussion of \texttt{try-with-resources}.)

One way to obtain a channel is by calling \texttt{getChannel()} on an object that supports channels. For example, \texttt{getChannel()} is supported by the following I/O classes:

<table>
<thead>
<tr>
<th>DatagramSocket</th>
<th>FileInputStream</th>
<th>FileOutputStream</th>
</tr>
</thead>
<tbody>
<tr>
<td>RandomAccessFile</td>
<td>ServerSocket</td>
<td>Socket</td>
</tr>
</tbody>
</table>

The specific type of channel returned depends upon the type of object \texttt{getChannel()} is called on. For example, when called on a \texttt{FileInputStream}, \texttt{FileOutputStream}, or \texttt{RandomAccessFile}, \texttt{getChannel()} returns a channel of type \texttt{FileChannel}. When called on a \texttt{Socket}, \texttt{getChannel()} returns a \texttt{SocketChannel}.

Another way to obtain a channel is to use one of the \texttt{static} methods defined by the \texttt{Files} class. For example, using \texttt{Files}, you can obtain a byte channel by calling \texttt{newByteChannel()}. It returns a \texttt{SeekableByteChannel}, which is an interface implemented by \texttt{FileChannel}. (The \texttt{Files} class is examined in detail later in this chapter.)

Channels such as \texttt{FileChannel} and \texttt{SocketChannel} support various \texttt{read()} and \texttt{write()} methods that enable you to perform I/O operations through the channel. For example, here are a few of the \texttt{read()} and \texttt{write()} methods defined for \texttt{FileChannel}:
All channels support additional methods that give you access to and control over the channel. For example, `FileChannel` supports methods to get or set the current position, transfer information between file channels, obtain the current size of the channel, and lock the channel, among others. `FileChannel` provides a static method called `open()`, which opens a file and returns a channel to it. This provides another way to obtain a channel. `FileChannel` also provides the `map()` method, which lets you map a file to a buffer.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>abstract int read(ByteBuffer bb) throws IOException</td>
<td>Reads bytes from the invoking channel into bb until the buffer is full or there is no more input. Returns the number of bytes actually read. Returns −1 when an attempt is made to read at the end of the file.</td>
</tr>
<tr>
<td>abstract int read(ByteBuffer bb, long start) throws IOException</td>
<td>Beginning at the file location specified by start, reads bytes from the invoking channel into bb until the buffer is full or there is no more input. The current position is unchanged. Returns the number of bytes actually read or −1 if start is beyond the end of the file.</td>
</tr>
<tr>
<td>abstract int write(ByteBuffer bb) throws IOException</td>
<td>Writes the contents of bb to the invoking channel, starting at the current position. Returns the number of bytes written.</td>
</tr>
<tr>
<td>abstract int write(ByteBuffer bb, long start) throws IOException</td>
<td>Beginning at the file location specified by start, writes the contents of bb to the invoking channel. The current position is unchanged. Returns the number of bytes written.</td>
</tr>
</tbody>
</table>

All channels support additional methods that give you access to and control over the channel. For example, `FileChannel` supports methods to get or set the current position, transfer information between file channels, obtain the current size of the channel, and lock the channel, among others. `FileChannel` provides a static method called `open()`, which opens a file and returns a channel to it. This provides another way to obtain a channel. `FileChannel` also provides the `map()` method, which lets you map a file to a buffer.

**Charsets and Selectors**

Two other entities used by NIO are charsets and selectors. A charset defines the way that bytes are mapped to characters. You can encode a sequence of characters into bytes using an encoder. You can decode a sequence of bytes into characters using a decoder.Charsets, encoders, and decoders are supported by classes defined in the `java.nio.charset` package. Because default encoders and decoders are provided, you will not often need to work explicitly with charsets.

A selector supports key-based, non-blocking, multiplexed I/O. In other words, selectors enable you to perform I/O through multiple channels. Selectors are supported by classes defined in the `java.nio.channels` package. Selectors are most applicable to socket-backed channels.

We will not use charsets or selectors in this chapter, but you might find them
useful in your own applications.

Enhancements Added by NIO.2

Beginning with JDK 7, the NIO system was substantially expanded and enhanced. In addition to support for the `try-with-resources` statement (which provides automatic resource management), the improvements included three new packages (`java.nio.file`, `java.nio.file.attribute`, and `java.nio.file.spi`); several new classes, interfaces, and methods; and direct support for stream-based I/O. The additions have greatly expanded the ways in which NIO can be used, especially with files. Several of the key additions are described in the following sections.

The Path Interface

Perhaps the single most important addition to the NIO system is the `Path` interface because it encapsulates a path to a file. As you will see, `Path` is the glue that binds together many of the NIO.2 file-based features. It describes a file’s location within the directory structure. `Path` is packaged in `java.nio.file`, and it inherits the following interfaces: `Watchable`, `Iterable<Path>`, and `Comparable<Path>`. `Watchable` describes an object that can be monitored for changes. The `Iterable` and `Comparable` interfaces were described earlier in this book.

`Path` declares a number of methods that operate on the path. A sampling is shown in Table 22-3. Pay special attention to the `getName()` method. It is used to obtain an element in a path. It works using an index. At index zero is the part of the path nearest the root, which is the leftmost element in a path. Subsequent indexes specify elements to the right of the root. The number of elements in a path can be obtained by calling `getNameCount()` . If you want to obtain a string representation of the entire path, simply call `toString()` . Notice that you can resolve a relative path into an absolute path by using the `resolve()` method.
Table 22-3  A Sampling of Methods Specified by Path

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>default boolean endsWith(String path)</td>
<td>Returns true if the invoking Path ends with the path specified by path. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean endsWith(Path path)</td>
<td>Returns true if the invoking Path ends with the path specified by path. Otherwise, returns false.</td>
</tr>
<tr>
<td>Path getFileName()</td>
<td>Returns the filename associated with the invoking Path.</td>
</tr>
<tr>
<td>Path getName(int idx)</td>
<td>Returns a Path object that contains the name of the path element specified by idx within the invoking object. The leftmost element is at index 0. This is the element nearest the root. The rightmost element is at getNameCount() – 1.</td>
</tr>
<tr>
<td>int getNameCount()</td>
<td>Returns the number of elements beyond the root directory in the invoking Path.</td>
</tr>
<tr>
<td>Path getParent()</td>
<td>Returns a Path that contains the entire path except for the name of the file specified by the invoking Path.</td>
</tr>
<tr>
<td>Path getRoot()</td>
<td>Returns the root of the invoking Path.</td>
</tr>
<tr>
<td>boolean isAbsolute()</td>
<td>Returns true if the invoking Path is absolute. Otherwise, returns false.</td>
</tr>
<tr>
<td>Path resolve(Path path)</td>
<td>If path is absolute, path is returned. Otherwise, if path does not contain a root, path is prefixed by the root specified by the invoking Path and the result is returned. If path is empty, the invoking Path is returned. Otherwise, the behavior is unspecified.</td>
</tr>
<tr>
<td>default Path resolve(String path)</td>
<td>If path is absolute, path is returned. Otherwise, if path does not contain a root, path is prefixed by the root specified by the invoking Path and the result is returned. If path is empty, the invoking Path is returned. Otherwise, the behavior is unspecified.</td>
</tr>
<tr>
<td>default boolean startsWith(String path)</td>
<td>Returns true if the invoking Path starts with the path specified by path. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean startsWith(Path path)</td>
<td>Returns true if the invoking Path starts with the path specified by path. Otherwise, returns false.</td>
</tr>
<tr>
<td>Path toAbsolutePath()</td>
<td>Returns the invoking Path as an absolute path.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Returns a string representation of the invoking Path.</td>
</tr>
</tbody>
</table>

One other point: When updating legacy code that uses the File class defined by
In Java, it is possible to convert a `File` instance into a `Path` instance by calling `toPath()` on the `File` object. Furthermore, it is possible to obtain a `File` instance by calling the `toFile()` method defined by `Path`.

### The Files Class

Many of the actions that you perform on a file are provided by static methods within the `Files` class. The file to be acted upon is specified by its `Path`. Thus, the `Files` methods use a `Path` to specify the file that is being operated upon. `Files` contains a wide array of functionality. For example, it has methods that let you open or create a file that has the specified path. You can obtain information about a `Path`, such as whether it is executable, hidden, or read-only. `Files` also supplies methods that let you copy or move files. A sampling is shown in Table 22-4. In addition to `IOException`, several other exceptions are possible. JDK 8 added these four methods to `Files`: `list()`, `walk()`, `lines()`, and `find()`. All return a `Stream` object. These methods help integrate NIO with the stream API defined by JDK 8 and described in Chapter 29.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static Path copy(Path src, Path dest, CopyOption ... how) throws IOException</td>
<td>Copies the file specified by src to the location specified by dest. The how parameter specifies how the copy will take place.</td>
</tr>
<tr>
<td>static Path createDirectory(Path path, FileAttribute&lt;?, ... &gt; attrs) throws IOException</td>
<td>Creates the directory whose path is specified by path. The directory attributes are specified by attrs.</td>
</tr>
<tr>
<td>static Path createFile(Path path, FileAttribute&lt;?, ... &gt; attrs) throws IOException</td>
<td>Creates the file whose path is specified by path. The file attributes are specified by attrs.</td>
</tr>
<tr>
<td>static void delete(Path path) throws IOException</td>
<td>Deletes the file whose path is specified by path.</td>
</tr>
<tr>
<td>static boolean exists(Path path, LinkOption ... opts)</td>
<td>Returns true if the file specified by path exists and false otherwise. If opts is not specified, then symbolic links are followed. To prevent the following of symbolic links, pass NOFOLLOW_LINKS to opts.</td>
</tr>
<tr>
<td>static boolean isDirectory(Path path, LinkOption ... opts)</td>
<td>Returns true if path specifies a directory and false otherwise. If opts is not specified, then symbolic links are followed. To prevent the following of symbolic links, pass NOFOLLOW_LINKS to opts.</td>
</tr>
<tr>
<td>static boolean isExecutable(Path path)</td>
<td>Returns true if the file specified by path is executable and false otherwise.</td>
</tr>
<tr>
<td>static boolean isHidden(Path path) throws IOException</td>
<td>Returns true if the file specified by path is hidden and false otherwise.</td>
</tr>
<tr>
<td>static boolean isReadable(Path path)</td>
<td>Returns true if the file specified by path can be read from and false otherwise.</td>
</tr>
<tr>
<td>static boolean isRegularFile(Path path, LinkOption ... opts)</td>
<td>Returns true if path specifies a file and false otherwise. If opts is not specified, then symbolic links are followed. To prevent the following of symbolic links, pass NOFOLLOW_LINKS to opts.</td>
</tr>
<tr>
<td>static boolean isWritable(Path path)</td>
<td>Returns true if the file specified by path can be written to and false otherwise.</td>
</tr>
<tr>
<td>static Path move(Path src, Path dest, CopyOption ... how) throws IOException</td>
<td>Moves the file specified by src to the location specified by dest. The how parameter specifies how the move will take place.</td>
</tr>
<tr>
<td>static SeekableByteChannel newByteChannel(Path path, OpenOption ... how) throws IOException</td>
<td>Opens the file specified by path, as specified by how. Returns a SeekableByteChannel to the file. This is a byte channel whose current position can be changed. SeekableByteChannel is implemented by FileChannel.</td>
</tr>
<tr>
<td>static DirectoryStream&lt;Path&gt; newDirectoryStream(Path path) throws IOException</td>
<td>Opens the directory specified by path. Returns a DirectoryStream linked to the directory.</td>
</tr>
</tbody>
</table>
Table 22-4  A Sampling of Methods Defined by Files

Notice that several of the methods in Table 22-4 take an argument of type `OpenOption`. This is an interface that describes how to open a file. It is implemented by the `StandardOpenOption` class, which defines an enumeration that has the values shown in Table 22-5.
Table 22-5  The Standard Open Options

The Paths Class

Because Path is an interface, not a class, you can’t create an instance of Path directly through the use of a constructor. Instead, you obtain a Path by calling a method that returns one. Frequently, you do this by using the get() method defined by the Paths class. There are two forms of get(). The one used in this chapter is shown here:

    static Path get(String pathname, String … parts)

It returns a Path that encapsulates the specified path. The path can be specified in two ways. First, if parts is not used, then the path must be specified in its entirety by pathname. Alternatively, you can pass the path in pieces, with the first part passed in pathname and the subsequent elements specified by the parts varargs parameter. In either case, if the path specified is syntactically invalid, get() will throw a

    InvalidPathException

The second form of get() creates a Path from a URI. It is shown here:

    static Path get(URI uri)
The **Path** corresponding to *uri* is returned.

It is important to understand that creating a **Path** to a file does not open or create a file. It simply creates an object that encapsulates the file’s directory path.

**The File Attribute Interfaces**

Associated with a file is a set of attributes. These attributes include such things as the file’s time of creation, the time of its last modification, whether the file is a directory, and its size. NIO organizes file attributes into several different interfaces. Attributes are represented by a hierarchy of interfaces defined in `java.nio.file.attribute`. At the top is **BasicFileAttributes**. It encapsulates the set of attributes that are commonly found in a variety of file systems. The methods defined by **BasicFileAttributes** are shown in Table 22-6.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>boolean isArchive()</code></td>
<td>Returns <code>true</code> if the file is flagged for archiving and <code>false</code> otherwise.</td>
</tr>
<tr>
<td><code>boolean isHidden()</code></td>
<td>Returns <code>true</code> if the file is hidden and <code>false</code> otherwise.</td>
</tr>
<tr>
<td><code>boolean isReadOnly()</code></td>
<td>Returns <code>true</code> if the file is read-only and <code>false</code> otherwise.</td>
</tr>
<tr>
<td><code>boolean isSystem()</code></td>
<td>Returns <code>true</code> if the file is flagged as a system file and <code>false</code> otherwise.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>FileTime creationTime()</td>
<td>Returns the time at which the file was created. If creation time is not provided by the file system, then an implementation-dependent value is returned.</td>
</tr>
<tr>
<td>Object fileKey()</td>
<td>Returns the file key. If not supported, null is returned.</td>
</tr>
<tr>
<td>boolean isDirectory()</td>
<td>Returns true if the file represents a directory.</td>
</tr>
<tr>
<td>boolean isOther()</td>
<td>Returns true if the file is not a file, symbolic link, or a directory.</td>
</tr>
<tr>
<td>boolean isRegularFile()</td>
<td>Returns true if the file is a normal file, rather than a directory or symbolic link.</td>
</tr>
<tr>
<td>boolean isSymbolicLink()</td>
<td>Returns true if the file is a symbolic link.</td>
</tr>
<tr>
<td>FileTime lastAccessTime()</td>
<td>Returns the time at which the file was last accessed. If the time of last access is not provided by the file system, then an implementation-dependent value is returned.</td>
</tr>
<tr>
<td>FileTime lastModifiedTime()</td>
<td>Returns the time at which the file was last modified. If the time of last modification is not provided by the file system, then an implementation-dependent value is returned.</td>
</tr>
<tr>
<td>long size()</td>
<td>Returns the size of the file.</td>
</tr>
</tbody>
</table>

Table 22-6  The Methods Defined by BasicFileAttributes

From BasicFileAttributes two interfaces are derived: DosFileAttributes and
PosixFileAttributes. DosFileAttributes describes those attributes related to the FAT file system as first defined by DOS. It defines the methods shown here:

PosixFileAttributes encapsulates attributes defined by the POSIX standards. (POSIX stands for Portable Operating System Interface.) It defines the methods shown here:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GroupPrincipal group()</td>
<td>Returns the file’s group owner.</td>
</tr>
<tr>
<td>UserPrincipal owner()</td>
<td>Returns the file’s owner.</td>
</tr>
<tr>
<td>Set&lt;PosixFilePermission&gt; permissions()</td>
<td>Returns the file’s permissions.</td>
</tr>
</tbody>
</table>

There are various ways to access a file’s attributes. First, you can obtain an object that encapsulates a file’s attributes by calling readAttributes(), which is a static method defined by Files. One of its forms is shown here:

```java
static <A extends BasicFileAttributes> A readAttributes(Path path, Class&lt;A&gt; attrType, LinkOption… opts)
throws IOException
```

This method returns a reference to an object that specifies the attributes associated with the file passed in path. The specific type of attributes is specified as a Class object in the attrType parameter. For example, to obtain the basic file attributes, pass BasicFileAttributes.class to attrType. For DOS attributes, use DosFileAttributes.class, and for POSIX attributes, use PosixFileAttributes.class. Optional link options are passed via opts. If not specified, symbolic links are followed. The method returns a reference to requested attributes. If the requested attribute type is not available, UnsupportedOperationException is thrown. Using the object returned, you can access the file’s attributes.

A second way to gain access to a file’s attributes is to call getFileAttributeView() defined by Files. NIO defines several attribute view interfaces, including AttributeView, BasicFileAttributeView, DosFileAttributeView, and PosixFileAttributeView, among others. Although we won’t be using attribute views in this chapter, they are a feature that you may find helpful in some situations.

In some cases, you won’t need to use the file attribute interfaces directly because the Files class offers static convenience methods that access several of the attributes. For example, Files includes methods such as isHidden() and isWritable().

It is important to understand that not all file systems support all possible attributes. For example, the DOS file attributes apply to the older FAT file system as first defined by DOS. The attributes that will apply to a wide variety of file systems
are described by BasicFileAttributes. For this reason, these attributes are used in the examples in this chapter.

The FileSystem, FileSystems, and FileStore Classes

You can easily access the file system through the FileSystem and FileSystems classes packaged in java.nio.file. In fact, by using the newFileSystem() method defined by FileSystems, it is even possible to obtain a new file system. The FileStore class encapsulates the file storage system. Although these classes are not used directly in this chapter, you may find them helpful in your own applications.

Using the NIO System

This section illustrates how to apply the NIO system to a variety of tasks. Before beginning, it is important to emphasize that with the release of JDK 7, the NIO subsystem was greatly expanded. As a result, its uses have also been greatly expanded. As mentioned, the enhanced version is sometimes referred to as NIO.2. Because the features added by NIO.2 are so substantial, they have changed the way that much NIO-based code is written and have increased the types of tasks to which NIO can be applied. Because of its importance, the remaining discussion and examples in this chapter utilize NIO.2 features and, therefore, require a modern version of Java.

REMEMBER The examples in this chapter require JDK 7 or later.

In the past, the primary purpose of NIO was channel-based I/O, and this is still a very important use. However, you can now use NIO for stream-based I/O and for performing file-system operations. As a result, the discussion of using NIO is divided into three parts:

• Using NIO for channel-based I/O
• Using NIO for stream-based I/O
• Using NIO for path and file system operations

Because the most common I/O device is the disk file, the rest of this chapter uses disk files in the examples. Because all file channel operations are byte-based, the type of buffers that we will be using are of type ByteBuffer.

Before you can open a file for access via the NIO system, you must obtain a Path that describes the file. One way to do this is to call the Paths.get() factory method, which was described earlier. The form of get() used in the examples is shown here:
static Path get(String pathname, String … parts)
Recall that the path can be specified in two ways. It can be passed in pieces, with the first part passed in pathname and the subsequent elements specified by the parts varargs parameter. Alternatively, the entire path can be specified in pathname and parts is not used. This is the approach used by the examples.

Use NIO for Channel-Based I/O
An important use of NIO is to access a file via a channel and buffers. The following sections demonstrate some techniques that use a channel to read from and write to a file.

Reading a File via a Channel
There are several ways to read data from a file using a channel. Perhaps the most common way is to manually allocate a buffer and then perform an explicit read operation that loads that buffer with data from the file. It is with this approach that we begin.

Before you can read from a file, you must open it. To do this, first create a Path that describes the file. Then use this Path to open the file. There are various ways to open the file depending on how it will be used. In this example, the file will be opened for byte-based input via explicit input operations. Therefore, this example will open the file and establish a channel to it by calling Files.newByteChannel(). The version of newByteChannel() that we will use has this general form:

    static SeekableByteChannel newByteChannel(Path path, OpenOption … how)
    throws IOException

It returns a SeekableByteChannel object, which encapsulates the channel for file operations. The Path that describes the file is passed in path. The how parameter specifies how the file will be opened. Because it is a varargs parameter, you can specify zero or more comma-separated arguments. (The valid values were discussed earlier and shown in Table 22-5.) If no arguments are specified, the file is opened for input operations. SeekableByteChannel is an interface that describes a channel that can be used for file operations. It is implemented by the FileChannel class. When the default file system is used, the returned object can be cast to FileChannel. You must close the channel after you have finished with it. Since all channels, including FileChannel, implement AutoCloseable, you can use a try-with-resources statement to close the file automatically instead of calling close() explicitly. This approach is used in the examples.

Next, you must obtain a buffer that will be used by the channel either by
wrapping an existing array or by allocating the buffer dynamically. The examples use allocation, but the choice is yours. Because file channels operate on byte buffers, we will use the allocate( ) method defined by ByteBuffer to obtain the buffer. It has this general form:

```java
static ByteBuffer allocate(int cap)
```
Here, cap specifies the capacity of the buffer. A reference to the buffer is returned.

After you have created the buffer, call read( ) on the channel, passing a reference to the buffer. The version of read( ) that we will use is shown next:

```java
int read(ByteBuffer buf) throws IOException
```
Each time it is called, read( ) fills the buffer specified by buf with data from the file. The reads are sequential, meaning that each call to read( ) reads the next buffer’s worth of bytes from the file. The read( ) method returns the number of bytes actually read. It returns –1 when there is an attempt to read at the end of the file.

The following program puts the preceding discussion into action by reading a file called test.txt through a channel using explicit input operations:

```java
// Use Channel I/O to read a file.
import java.io.*;
import java.nio.*;
import java.nio.channels.*;
import java.nio.file.*;

public class ExplicitChannelRead {
    public static void main(String args[]) {
        int count;
        Path filepath = null;

        // First, obtain a path to the file.
        try {
            filepath = Paths.get("test.txt");
        } catch(InvalidPathException e) {
            System.out.println("Path Error " + e);
            return;
        }

        // Next, obtain a channel to that file within a try-with-resources block.
        try (SeekableByteChannel fChan = Files.newByteChannel(filepath)) {
            
```
Here is how the program works. First, a Path object is obtained that contains the relative path to a file called test.txt. A reference to this object is assigned to filepath. Next, a channel connected to the file is obtained by calling newByteChannel(), passing in filepath. Because no open option is specified, the file is opened for reading. Notice that this channel is the object managed by the try-with-resources statement. Thus, the channel is automatically closed when the block ends. The program then calls the allocate() method of ByteBuffer to allocate a buffer that will hold the contents of the file when it is read. A reference to this buffer is stored in mBuf. The contents of the file are then read, one buffer at a time, into mBuf through a call to read(). The number of bytes read is stored in count. Next, the buffer is rewound through a call to rewind(). This call is necessary because the current position is at the end of the buffer after the call to read(). It must be reset to the start of the buffer in order for the bytes in mBuf to be read by calling get(). (Recall that get() is defined by ByteBuffer.) Because mBuf is a byte buffer, the values returned
by `get()` are bytes. They are cast to `char` so the file can be displayed as text.
(Alternatively, it is possible to create a buffer that encodes the bytes into characters
and then read that buffer.) When the end of the file has been reached, the value
returned by `read()` will be –1. When this occurs, the program ends, and the channel
is automatically closed.

As a point of interest, notice that the program obtains the `Path` within one `try`
block and then uses another `try` block to obtain and manage a channel linked to that
path. Although there is nothing wrong, per se, with this approach, in many cases, it
can be streamlined so that only one `try` block is needed. In this approach, the calls to
`Paths.get()` and `newByteChannel()` are sequenced together. For example, here is a
reworked version of the program that uses this approach:

```java
// A more compact way to open a channel.
import java.io.*;
import java.nio.*;
import java.nio.channels.*;
import java.nio.file.*;

public class ExplicitChannelRead {
    public static void main(String args[]) {
        int count;

        // Here, the channel is opened on the Path returned by Paths.get()
        // There is no need for the filepath variable.
        try (SeekableByteChannel fChan =
             Files.newByteChannel(Paths.get("test.txt"))
        )
        {
            // Allocate a buffer.
            ByteBuffer mBuf = ByteBuffer.allocate(128);
```
In this version, the variable `filepath` is not needed and both exceptions are handled by the same `try` statement. Because this approach is more compact, it is the approach used in the rest of the examples in this chapter. Of course, in your own code, you may encounter situations in which the creation of a `Path` object needs to be separate from the acquisition of a channel. In these cases, the previous approach can be used.

Another way to read a file is to map it to a buffer. The advantage is that the buffer automatically contains the contents of the file. No explicit read operation is necessary. To map and read the contents of a file, follow this general procedure. First, obtain a `Path` object that encapsulates the file as previously described. Next, obtain a channel to that file by calling `Files.newByteChannel()`, passing in the `Path` and casting the returned object to `FileChannel`. As explained, `newByteChannel()` returns a `SeekableByteChannel`. When using the default file system, this object can be cast to `FileChannel`. Then, map the channel to a buffer by calling `map()` on the channel. The `map()` method is defined by `FileChannel`. This is why the cast to `FileChannel` is needed. The `map()` function is shown here:

```java
MappedByteBuffer map(FileChannel.MapMode how,
```
The `map()` method causes the data in the file to be mapped into a buffer in memory. The value in `how` determines what type of operations are allowed. It must be one of these values:

| MapMode.READ_ONLY | MapMode.READ_WRITE | MapMode.PRIVATE |

For reading a file, use `MapMode.READ_ONLY`. To read and write, use `MapMode.READ_WRITE`. `MapMode.PRIVATE` causes a private copy of the file to be made, and changes to the buffer do not affect the underlying file. The location within the file to begin mapping is specified by `pos`, and the number of bytes to map are specified by `size`. A reference to this buffer is returned as a `MappedByteBuffer`, which is a subclass of `ByteBuffer`. Once the file has been mapped to a buffer, you can read the file from that buffer. Here is an example that illustrates this approach:
In the program, a Path to the file is created and then opened via newByteChannel( ). The channel is cast to FileChannel and stored in fChan. Next, the size of the file is obtained by calling size( ) on the channel. Then, the entire file is mapped into memory by calling map( ) on fChan and a reference to the buffer is stored in mBuf. Notice that mBuf is declared as a reference to a MappedByteBuffer. The bytes in mBuf are read by calling get( ).

Writing to a File via a Channel
As is the case when reading from a file, there are also several ways to write data to a
file using a channel. We will begin with one of the most common. In this approach, you manually allocate a buffer, write data to that buffer, and then perform an explicit write operation to write that data to a file.

Before you can write to a file, you must open it. To do this, first obtain a Path that describes the file and then use this Path to open the file. In this example, the file will be opened for byte-based output via explicit output operations. Therefore, this example will open the file and establish a channel to it by calling Files.newByteChannel(). As shown in the previous section, the newByteChannel() method that we will use has this general form:

\[
\text{static SeekableByteChannel newByteChannel(Path path, OpenOption \ldots how)}
\]

\[\text{throws IOException}\]

It returns a SeekableByteChannel object, which encapsulates the channel for file operations. To open a file for output, the how parameter must specify StandardOpenOption.WRITE. If you want to create the file if it does not already exist, then you must also specify StandardOpenOption.CREATE. (Other options, which are shown in Table 22-5, are also available.) As explained in the previous section, SeekableByteChannel is an interface that describes a channel that can be used for file operations. It is implemented by the FileChannel class. When the default file system is used, the return object can be cast to FileChannel. You must close the channel after you have finished with it.

Here is one way to write to a file through a channel using explicit calls to write(). First, obtain a Path to the file and then open it with a call to newByteChannel(), casting the result to FileChannel. Next, allocate a byte buffer and write data to that buffer. Before the data is written to the file, call rewind() on the buffer to set its current position to zero. (Each output operation on the buffer increases the current position. Thus, it must be reset prior to writing to the file.) Then, call write() on the channel, passing in the buffer. The following program demonstrates this procedure. It writes the alphabet to a file called test.txt.
It is useful to emphasize an important aspect of this program. As mentioned, after
data is written to \texttt{mBuf}, but before it is written to the file, a call to \texttt{rewind( )} on
\texttt{mBuf} is made. This is necessary in order to reset the current position to zero after
data has been written to \texttt{mBuf}. Remember, each call to \texttt{put( )} on \texttt{mBuf} advances the
current position. Therefore, it is necessary for the current position to be reset to the
start of the buffer before calling \texttt{write( )}. If this is not done, \texttt{write( )} will think that

```java
// Write to a file using NIO.

import java.io.*;
import java.nio.*;
import java.nio.channels.*;
import java.nio.file.*;

public class ExplicitChannelWrite {
    public static void main(String args[]) {

        // Obtain a channel to a file within a try-with-resources block.
        try (FileChannel fChan = (FileChannel)
                Files.newByteChannel(Paths.get("test.txt"),
                StandardOpenOption.WRITE,
                StandardOpenOption.CREATE) )
        {
            // Create a buffer.
            ByteBuffer mBuf = ByteBuffer.allocate(26);

            // Write some bytes to the buffer.
            for(int i=0; i<26; i++)
                mBuf.put((byte)('A' + i));

            // Reset the buffer so that it can be written.
            mBuf.rewind();

            // Write the buffer to the output file.
            fChan.write(mBuf);
        }
        catch(InvalidPathException e) {
            System.out.println("Path Error " + e);
        }
        catch (IOException e) {
            System.out.println("I/O Error: " + e);
            System.exit(1);
        }
    }
}
```
there is no data in the buffer.

Another way to handle the resetting of the buffer between input and output operations is to call `flip()` instead of `rewind()`. The `flip()` method sets the value of the current position to zero and the limit to the previous current position. In the preceding example, because the capacity of the buffer equals its limit, `flip()` could have been used instead of `rewind()`. However, the two methods are not interchangeable in all cases.

In general, you must reset the buffer between read and write operations. For example, assuming the preceding example, the following loop will write the alphabet to the file three times. Pay special attention to the calls to `rewind()`.

```java
for(int h=0; h<3; h++) {
    // Write some bytes to the buffer.
    for(int i=0; i<26; i++)
        mBuf.put((byte)('A' + i));

    // Rewind the buffer so that it can be written.
    mBuf.rewind();

    // Write the buffer to the output file.
    fChan.write(mBuf);

    // Rewind the buffer so that it can be written to again.
    mBuf.rewind();
}
```

Notice that `rewind()` is called between each read and write operation.

One other thing about the program warrants mentioning: When the buffer is written to the file, the first 26 bytes in the file will contain the output. If the file `test.txt` was preexisting, then after the program executes, the first 26 bytes of `test.txt` will contain the alphabet, but the remainder of the file will remain unchanged.

Another way to write to a file is to map it to a buffer. The advantage to this approach is that the data written to the buffer will automatically be written to the file. No explicit write operation is necessary. To map and write the contents of a file, we will use this general procedure. First, obtain a `Path` object that encapsulates the file and then create a channel to that file by calling `Files.newByteChannel()`, passing in the `Path`. Cast the reference returned by `newByteChannel()` to `FileChannel`. Next, map the channel to a buffer by calling `map()` on the channel. The `map()` method was described in detail in the previous section. It is summarized here for your convenience. Here is its general form:

```java
MappedByteBuffer map(FileChannel.MapMode how,
```
The `map()` method causes the data in the file to be mapped into a buffer in memory. The value in `how` determines what type of operations are allowed. For writing to a file, `how` must be `MapMode.READ_WRITE`. The location within the file to begin mapping is specified by `pos`, and the number of bytes to map are specified by `size`. A reference to this buffer is returned. Once the file has been mapped to a buffer, you can write data to that buffer, and it will automatically be written to the file. Therefore, no explicit write operations to the channel are necessary.

Here is the preceding program reworked so that a mapped file is used. Notice that in the call to `newByteChannel()`, the open option `StandardOpenOption.READ` has been added. This is because a mapped buffer can either be read-only or read/write. Thus, to write to the mapped buffer, the channel must be opened as read/write.
As you can see, there are no explicit write operations to the channel itself. Because mBuf is mapped to the file, changes to mBuf are automatically reflected in the underlying file.

**Copying a File Using NIO**

NIO simplifies several types of file operations. Although we can’t examine them all, an example will give you an idea of what is available. The following program copies a file using a call to a single NIO method: `copy()`, which is a static method defined by Files. It has several forms. Here is the one we will be using:
static Path copy(Path src, Path dest, CopyOption ... how) throws IOException

The file specified by src is copied to the file specified by dest. How the copy is performed is specified by how. Because it is a varargs parameter, it can be missing. If specified, it can be one or more of these values, which are valid for all file systems:

<table>
<thead>
<tr>
<th>StandardCopyOption.COPY_ATTRIBUTES</th>
<th>Request that the file's attributes be copied.</th>
</tr>
</thead>
<tbody>
<tr>
<td>StandardLinkOption.NOFOLLOW_LINKS</td>
<td>Do not follow symbolic links.</td>
</tr>
<tr>
<td>StandardCopyOption.REPLACE_EXISTING</td>
<td>Overwrite a preexisting file.</td>
</tr>
</tbody>
</table>

Other options may be supported, depending on the implementation.

The following program demonstrates copy(). The source and destination files are specified on the command line, with the source file specified first. Notice how short the program is. You might want to compare this version of the file copy program to the one found in Chapter 13. As you will find, the part of the program that actually copies the file is substantially shorter in the NIO version shown here.

```java
// Copy a file using NIO.
import java.io.*;
import java.nio.*;
import java.nio.channels.*;
import java.nio.file.*;

public class NIOCopy {

    public static void main(String args[]) {

        if(args.length != 2) {
            System.out.println("Usage: Copy from to");
            return;
        }

        try {
            Path source = Paths.get(args[0]);
            Path target = Paths.get(args[1]);
```
Use NIO for Stream-Based I/O

Beginning with NIO.2, you can use NIO to open an I/O stream. Once you have a Path, open a file by calling newInputStream() or newOutputStream(), which are static methods defined by Files. These methods return a stream connected to the specified file. In either case, the stream can then be operated on in the way described in Chapter 20, and the same techniques apply. The advantage of using Path to open a file is that all of the features defined by NIO are available for your use.

To open a file for stream-based input, use Files.newInputStream(). It is shown here:

```java
static InputStream newInputStream(Path path, OpenOption … how)
    throws IOException
```

Here, path specifies the file to open and how specifies how the file will be opened. It must be one or more of the values defined by StandardOpenOption, described earlier. (Of course, only those options that relate to an input stream will apply.) If no options are specified, then the file is opened as if StandardOpenOption.READ were passed.

Once opened, you can use any of the methods defined by InputStream. For example, you can use read() to read bytes from the file.

The following program demonstrates the use of NIO-based stream I/O. It reworks the ShowFile program from Chapter 13 so that it uses NIO features to open the file and obtain a stream. As you can see, it is very similar to the original, except for the use of Path and newInputStream().

```java
// Copy the file.
Files.copy(source, target, StandardCopyOption.REPLACE_EXISTING);

} catch(InvalidPathException e) {
    System.out.println("Path Error " + e);
} catch (IOException e) {
    System.out.println("I/O Error " + e);
}
```
Because the stream returned by `newInputStream()` is a normal stream, it can be used like any other stream. For example, you can wrap the stream inside a buffered stream, such as a `BufferedInputStream`, to provide buffering, as shown here:

```java
new BufferedInputStream(Files.newInputStream(Paths.get(args[0])))
```
Now, all reads will be automatically buffered.

To open a file for output, use `Files.newOutputStream()`. It is shown here:

```java
static OutputStream newOutputStream(Path path, OpenOption … how)
    throws IOException
```

Here, `path` specifies the file to open and `how` specifies how the file will be opened. It must be one or more of the values defined by `StandardOpenOption`, described earlier. (Of course, only those options that relate to an output stream will apply.) If no options are specified, then the file is opened as if `StandardOpenOption.WRITE, StandardOpenOption.CREATE, and StandardOpenOption.TRUNCATE_EXISTING` were passed.

The methodology for using `newOutputStream()` is similar to that shown previously for `newInputStream()`. Once opened, you can use any of the methods defined by `OutputStream`. For example, you can use `write()` to write bytes to the file. You can also wrap the stream inside a `BufferedOutputStream` to buffer the stream.

The following program shows `newOutputStream()` in action. It writes the alphabet to a file called `test.txt`. Notice the use of buffered I/O.

```java
// Demonstrate NIO-based, stream output.

import java.io.*;
import java.nio.file.*;

class NIOStreamWrite {
    public static void main(String args[]) {
        // Open the file and obtain a stream linked to it.
        try {
            OutputStream fout =
                new BufferedOutputStream(
                    Files.newOutputStream(Paths.get("test.txt")))
            ;

            // Write some bytes to the stream.
            for(int i=0; i < 26; i++)
                fout.write((byte)('A' + i));

        } catch(InvalidPathException e) {
            System.out.println("Path Error " + e);
        } catch(IOException e) {
            System.out.println("I/O Error: " + e);
        }
    }
}
```
Use NIO for Path and File System Operations

At the beginning of Chapter 21, the File class in the java.io package was examined. As explained there, the File class deals with the file system and with the various attributes associated with a file, such as whether a file is read-only, hidden, and so on. It was also used to obtain information about a file’s path. Although the File class is still perfectly acceptable, the interfaces and classes defined by NIO.2 offer a better way to perform these functions. The benefits include support for symbolic links, better support for directory tree traversal, and improved handling of metadata, among others. The following sections show samples of two common file system operations: obtaining information about a path and file and getting the contents of a directory.

REMEMBER If you want to update older code that uses java.io.File to the new Path interface, you can use the toPath() method to obtain a Path instance from a File instance.

Obtain Information About a Path and a File

Information about a path can be obtained by using methods defined by Path. Some attributes associated with the file described by a Path (such as whether or not the file is hidden) are obtained by using methods defined by Files. The Path methods used here are getName(), getParent(), and toAbsolutePath(). Those provided by Files are isExecutable(), isHidden(), isReadable(), isWritable(), and exists(). These are summarized in Tables 22-3 and 22-4, shown earlier.

CAUTION Methods such as isExecutable(), isReadable(), isWritable(), and exists() must be used with care because the state of the file system may change after the call, in which case a program malfunction could occur. Such a situation could have security implications.

Other file attributes are obtained by requesting a list of attributes by calling Files.readAttributes(). In the program, this method is called to obtain the BasicFileAttributes associated with a file, but the general approach applies to other types of attributes.

The following program demonstrates several of the Path and Files methods, along with several methods provided by BasicFileAttributes. This program assumes that a file called test.txt exists in a directory called examples, which must be a subdirectory of the current directory.
// Obtain information about a path and a file.
import java.io.*;
import java.nio.file.*;
import java.nio.file.attribute.*;

class PathDemo {
    public static void main(String args[]) {
        Path filepath = Paths.get("examples\test.txt");

        System.out.println("File Name: " + filepath.getName(1));
        System.out.println("Path: " + filepath);
        System.out.println("Absolute Path: " + filepath.toAbsolutePath());
        System.out.println("Parent: " + filepath.getParent());

        if(Files.exists(filepath))
            System.out.println("File exists");
        else
            System.out.println("File does not exist");
    }
}
try {
    if(Files.isHidden(filepath))
        System.out.println("File is hidden");
    else
        System.out.println("File is not hidden");
} catch(InterruptedException e) {
    System.out.println("I/O Error: " + e);
}

Files.isWritable(filepath);
System.out.println("File is writable");

Files.isReadable(filepath);
System.out.println("File is readable");

try {
    BasicFileAttributes attrs =
        Files.readAttributes(filepath, BasicFileAttributes.class);

    if(attrs.isDirectory())
        System.out.println("The file is a directory");
    else
        System.out.println("The file is not a directory");

    if(attrs.isRegularFile())
        System.out.println("The file is a normal file");
    else
        System.out.println("The file is not a normal file");

    if(attrs.isSymbolicLink())
        System.out.println("The file is a symbolic link");
    else
        System.out.println("The file is not a symbolic link");

    System.out.println("File last modified: " + attrs.lastModifiedTime());
    System.out.println("File size: " + attrs.size() + " Bytes");
} catch(InterruptedException e) {
    System.out.println("Error reading attributes: " + e);
}

If you execute this program from a directory called MyDir, which has a subdirectory called examples, and the examples directory contains the test.txt file, then you will
If you are using a computer that supports the FAT file system (i.e., the DOS file system), then you might want to try using the methods defined by 
**DosFileAttributes**. If you are using a POSIX-compatible system, then try using **PosixFileAttributes**.

**List the Contents of a Directory**

If a path describes a directory, then you can read the contents of that directory by using static methods defined by **Files**. To do this, you first obtain a directory stream by calling **newDirectoryStream()**, passing in a **Path** that describes the directory. One form of **newDirectoryStream()** is shown here:

```java
static DirectoryStream<Path> newDirectoryStream(Path dirPath)
throws IOException
```

Here, **dirPath** encapsulates the path to the directory. The method returns a **DirectoryStream<Path>** object that can be used to obtain the contents of the directory. It will throw an **IOException** if an I/O error occurs and a **NotDirectoryException** (which is a subclass of **IOException**) if the specified path is not a directory. A **SecurityException** is also possible if access to the directory is not permitted.

**DirectoryStream<Path>** implements **AutoCloseable**, so it can be managed by a try-with-resources statement. It also implements **Iterable<Path>**. This means that you can obtain the contents of the directory by iterating over the **DirectoryStream** object. When iterating, each directory entry is represented by a **Path** instance. An easy way to iterate over a **DirectoryStream** is to use a for-each style for loop. It is
important to understand, however, that the iterator implemented by
DirectoryStream<Path> can be obtained only once for each instance. Thus, the
iterator() method can be called only once, and a for-each loop can be executed only
once.

The following program displays the contents of a directory called MyDir:
Here is sample output from the program:
You can filter the contents of a directory in two ways. The easiest is to use this version of `newDirectoryStream()`:

```java
static DirectoryStream<Path> newDirectoryStream(Path dirPath, String wildcard)
```

This obtains a directory stream that contains only those files whose names begin with either "Path" or "Dir" and use either the "java" or "class" extension. Thus, it would match names like `DirList.java` and `PathDemo.java`, but not `MyPathDemo.java`, for example.

Another way to filter a directory is to use this version of `newDirectoryStream()`:

```java
static DirectoryStream<Path> newDirectoryStream(Path dirPath,
        DirectoryStream.Filter<? super Path> filefilter)
```

Here, `DirectoryStream.Filter` is an interface that specifies the following method:

```java
    boolean accept(T entry) throws IOException
```

In this case, `T` will be `Path`. If you want to include `entry` in the list, return `true`. 
Otherwise, return false. This form of `newDirectoryStream()` offers the advantage of being able to filter a directory based on something other than a filename. For example, you can filter based on size, creation date, modification date, or attribute, to name a few.

The following program demonstrates the process. It will list only those files that are writable.

```java
// Display a directory of only those files that are writable.

import java.io.*;
import java.nio.file.*;
import java.nio.file.attribute.*;

class DirList {
    public static void main(String args[]) {
        String dirname = "\\MyDir";

        // Create a filter that returns true only for writable files.
        DirectoryStream.Filter<Path> how = new DirectoryStream.Filter<Path>() {
            public boolean accept(Path filename) throws IOException {
                if(Files.isWritable(filename)) return true;
                return false;
            }
        };

        // Obtain and manage a directory stream of writable files.
        try (DirectoryStream<Path> dirstrm =
            Files.newDirectoryStream(Paths.get(dirname), how)) {
            System.out.println("Directory of " + dirname);
        }
    }
}
```
Use walkFileTree( ) to List a Directory Tree

The preceding examples have obtained the contents of only a single directory. However, sometimes you will want to obtain a list of the files in a directory tree. In the past, this was quite a chore, but NIO.2 makes it easy because now you can use the \texttt{walkFileTree( )} method defined by \texttt{Files} to process a directory tree. It has two forms. The one used in this chapter is shown here:

\begin{verbatim}
    static Path walkFileTree(Path root, FileVisitor<? super Path> fv)
    throws IOException
    {
        for(Path entry : dirstrm) {
            BasicFileAttributes attrs =
                Files.readAttributes(entry, BasicFileAttributes.class);

            if(attrs.isDirectory())
                System.out.print("<DIR> ");
            else
                System.out.print(" ");

            System.out.println(entry.getName(1));
        }
    }
\end{verbatim}

The path to the starting point of the directory walk is passed in \texttt{root}. An instance of \texttt{FileVisitor} is passed in \texttt{fv}. The implementation of \texttt{FileVisitor} determines how the directory tree is traversed, and it gives you access to the directory information. If an I/O error occurs, an \texttt{IOException} is thrown. A \texttt{SecurityException} is also possible.

\texttt{FileVisitor} is an interface that defines how files are visited when a directory tree is traversed. It is a generic interface that is declared like this:

\begin{verbatim}
    interface FileVisitor<T>
\end{verbatim}

For use in \texttt{walkFileTree( )}, \texttt{T} will be \texttt{Path} (or any type derived from \texttt{Path}). \texttt{FileVisitor} defines the following methods:
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FileVisitResult&lt;br&gt; postVisitDirectory(T dir, IOException exc)&lt;br&gt; throws IOException</td>
<td>Called after a directory has been visited. The directory is passed in <code>dir</code>, and any <code>IOException</code> is passed in <code>exc</code>. If <code>exc</code> is <code>null</code>, no exception occurred. The result is returned.</td>
</tr>
<tr>
<td>FileVisitResult&lt;br&gt; preVisitDirectory(T dir,&lt;br&gt; BasicFileAttributes attribs)&lt;br&gt; throws IOException</td>
<td>Called before a directory is visited. The directory is passed in <code>dir</code>, and the attributes associated with the directory are passed in <code>attribs</code>. The result is returned. To examine the directory, return <code>FileVisitResult.CONTINUE</code>.</td>
</tr>
<tr>
<td>FileVisitResult&lt;br&gt; visitFile(T file, BasicFileAttributes attribs)&lt;br&gt; throws IOException</td>
<td>Called when a file is visited. The file is passed in <code>file</code>, and the attributes associated with the file are passed in <code>attribs</code>. The result is returned.</td>
</tr>
<tr>
<td>FileVisitResult&lt;br&gt; visitFailed(T file, IOException exc)&lt;br&gt; throws IOException</td>
<td>Called when an attempt to visit a file fails. The file that failed is passed in <code>file</code>, and the <code>IOException</code> is passed in <code>exc</code>. The result is returned.</td>
</tr>
</tbody>
</table>

Notice that each method returns a `FileVisitResult`. This enumeration defines the following values:

<table>
<thead>
<tr>
<th>CONTINUE</th>
<th>SKIP_SIBLINGS</th>
<th>SKIP_SUBTREE</th>
<th>TERMINATE</th>
</tr>
</thead>
</table>

In general, to continue traversing the directory and subdirectories, a method should return `CONTINUE`. For `preVisitDirectory()`, return `SKIP_SIBLINGS` to bypass the directory and its siblings and prevent `postVisitDirectory()` from being called. To bypass just the directory and subdirectories, return `SKIP_SUBTREE`. To stop the directory traversal, return `TERMINATE`.

Although it is certainly possible to create your own visitor class that implements these methods defined by `FileVisitor`, you won’t normally do so because a simple implementation is provided by `SimpleFileVisitor`. You can just override the default implementation of the method or methods in which you are interested. Here is a short example that illustrates the process. It displays all files in the directory tree that has `\MyDir` as its root. Notice how short this program is.
Here is sample output produced by the program when used on the same `MyDir` directory shown earlier. In this example, the subdirectory called `examples` contains one file called `MyProgram.java`.

Directory tree starting with \MyDir:

\MyDir\DirList.class
\MyDir\DirList.java
\MyDir\examples\MyProgram.java
\MyDir\Test.txt

In the program, the class `MyFileVisitor` extends `SimpleFileVisitor`, overriding only the `visitFile()` method. In this example, `visitFile()` simply displays the files, but
more sophisticated functionality is easy to achieve. For example, you could filter the files or perform actions on the files, such as copying them to a backup device. For the sake of clarity, a named class was used to override `visitFile()`, but you could also use an anonymous inner class.

One last point: It is possible to watch a directory for changes by using `java.nio.file.WatchService`.
CHAPTER
23 Networking

Since its beginning, Java has been associated with Internet programming. There are a number of reasons for this, not the least of which is its ability to generate secure, cross-platform, portable code. However, one of the most important reasons that Java is the premier language for network programming are the classes defined in the java.net package. They provide an easy-to-use means by which programmers of all skill levels can access network resources.

This chapter explores the java.net package. It is important to emphasize that networking is a very large and at times complicated topic. It is not possible for this book to discuss all of the capabilities contained in java.net. Instead, this chapter focuses on several of its core classes and interfaces.

Networking Basics

Before we begin, it will be useful to review some key networking concepts and terms. At the core of Java’s networking support is the concept of a socket. A socket identifies an endpoint in a network. The socket paradigm was part of the 4.2BSD Berkeley UNIX release in the early 1980s. Because of this, the term Berkeley socket is also used. Sockets are at the foundation of modern networking because a socket allows a single computer to serve many different clients at once, as well as to serve many different types of information. This is accomplished through the use of a port, which is a numbered socket on a particular machine. A server process is said to "listen" to a port until a client connects to it. A server is allowed to accept multiple clients connected to the same port number, although each session is unique. To manage multiple client connections, a server process must be multithreaded or have some other means of multiplexing the simultaneous I/O.

Socket communication takes place via a protocol. Internet Protocol (IP) is a low-level routing protocol that breaks data into small packets and sends them to an address across a network, which does not guarantee to deliver said packets to the destination. Transmission Control Protocol (TCP) is a higher-level protocol that manages to robustly string together these packets, sorting and retransmitting them as necessary to reliably transmit data. A third protocol, User Datagram Protocol (UDP), sits next to TCP and can be used directly to support fast, connectionless, unreliable transport of packets.
Once a connection has been established, a higher-level protocol ensues, which is dependent on which port you are using. TCP/IP reserves the lower 1,024 ports for specific protocols. Many of these will seem familiar to you if you have spent any time surfing the Internet. Port number 21 is for FTP; 23 is for Telnet; 25 is for e-mail; 43 is for whois; 80 is for HTTP; 119 is for netnews—and the list goes on. It is up to each protocol to determine how a client should interact with the port.

For example, HTTP is the protocol that web browsers and servers use to transfer hypertext pages and images. It is a quite simple protocol for a basic page-browsing web server. Here’s how it works. When a client requests a file from an HTTP server, an action known as a hit, it simply sends the name of the file in a special format to a predefined port and reads back the contents of the file. The server also responds with a status code to tell the client whether or not the request can be fulfilled and why.

A key component of the Internet is the address. Every computer on the Internet has one. An Internet address is a number that uniquely identifies each computer on the Net. Originally, all Internet addresses consisted of 32-bit values, organized as four 8-bit values. This address type was specified by IPv4 (Internet Protocol, version 4). However, a new addressing scheme, called IPv6 (Internet Protocol, version 6) has come into play. IPv6 uses a 128-bit value to represent an address, organized into eight 16-bit chunks. Although there are several reasons for and advantages to IPv6, the main one is that it supports a much larger address space than does IPv4. Fortunately, when using Java, you won’t normally need to worry about whether IPv4 or IPv6 addresses are used because Java handles the details for you.

Just as the numbers of an IP address describe a network hierarchy, the name of an Internet address, called its domain name, describes a machine’s location in a name space. For example, www.HerbSchildt.com is in the COM top-level domain (used by U.S. commercial sites); it is called HerbSchildt, and www identifies the server for web requests. An Internet domain name is mapped to an IP address by the Domain Naming Service (DNS). This enables users to work with domain names, but the Internet operates on IP addresses.

**The Networking Classes and Interfaces**

Java supports TCP/IP both by extending the already established stream I/O interface introduced in Chapter 21 and by adding the features required to build I/O objects across the network. Java supports both the TCP and UDP protocol families. TCP is used for reliable stream-based I/O across the network. UDP supports a simpler, hence faster, point-to-point datagram-oriented model. The classes contained in the java.net package are shown here:
Beginning with JDK 9, the `java.net` package is part of the `java.base` module. In the sections that follow, we will examine the main networking classes and show several examples that apply to them. Once you understand these core networking classes, you will be able to easily explore the others on your own.

## InetAddress

The `InetAddress` class is used to encapsulate both the numerical IP address and the domain name for that address. You interact with this class by using the name of an IP host, which is more convenient and understandable than its IP address. The `InetAddress` class hides the number inside. `InetAddress` can handle both IPv4 and
IPv6 addresses.

**Factory Methods**

The `InetAddress` class has no visible constructors. To create an `InetAddress` object, you have to use one of the available factory methods. As explained earlier in this book, *factory methods* are merely a convention whereby static methods in a class return an instance of that class. This is done in lieu of overloading a constructor with various parameter lists when having unique method names makes the results much clearer. Three commonly used `InetAddress` factory methods are shown here:

- `static InetAddress getLocalHost( )
  throws UnknownHostException`
- `static InetAddress getByName(String hostName)
  throws UnknownHostException`
- `static InetAddress[ ] getAllByName(String hostName)
  throws UnknownHostException`

The `getLocalHost( )` method simply returns the `InetAddress` object that represents the local host. The `getByName( )` method returns an `InetAddress` for a host name passed to it. If these methods are unable to resolve the host name, they throw an `UnknownHostException`.

On the Internet, it is common for a single name to be used to represent several machines. In the world of web servers, this is one way to provide some degree of scaling. The `getAllByName( )` factory method returns an array of `InetAddress`es that represent all of the addresses that a particular name resolves to. It will also throw an `UnknownHostException` if it can’t resolve the name to at least one address.

`InetAddress` also includes the factory method `getByAddress( )`, which takes an IP address and returns an `InetAddress` object. Either an IPv4 or an IPv6 address can be used.

The following example prints the addresses and names of the local machine and two Internet web sites:
Instance Methods

The InetAddress class has several other methods, which can be used on the objects returned by the methods just discussed. Here are some of the more commonly used methods:

```java
// Demonstrate InetAddress.
import java.net.*;

class InetAddressTest
{
    public static void main(String args[]) throws UnknownHostException {
        InetAddress Address = InetAddress.getHostName();
        System.out.println(Address);

        Address = InetAddress.getByName("www.HerbSchilt.com");
        System.out.println(Address);

        InetAddress SW[] = InetAddress.getAllByName("www.nba.com");
        for (int i=0; i<SW.length; i++)
            System.out.println(SW[i]);
    }
}

Here is the output produced by this program. (Of course, the output you see may be slightly different.)
default/166.203.115.212
www.HerbSchilt.com/216.92.65.4
www.nba.com/23.3.98.74
www.nba.com/23.3.98.75
```
Internet addresses are looked up in a series of hierarchically cached servers. That means that your local computer might know a particular name-to-IP-address mapping automatically, such as for itself and nearby servers. For other names, it may ask a local DNS server for IP address information. If that server doesn’t have a particular address, it can go to a remote site and ask for it. This can continue all the way up to the root server. This process might take a long time, so it is wise to structure your code so that you cache IP address information locally rather than look it up repeatedly.

### Inet4Address and Inet6Address

Java includes support for both IPv4 and IPv6 addresses. Because of this, two subclasses of `InetAddress` were created: `Inet4Address` and `Inet6Address`. `Inet4Address` represents a traditional-style IPv4 address. `Inet6Address` encapsulates a newer IPv6 address. Because they are subclasses of `InetAddress`, an `InetAddress` reference can refer to either. This is one way that Java was able to add IPv6 functionality without breaking existing code or adding many more classes. For the most part, you can simply use `InetAddress` when working with IP addresses because it can accommodate both styles.

### TCP/IP Client Sockets

TCP/IP sockets are used to implement reliable, bidirectional, persistent, point-to-point, stream-based connections between hosts on the Internet. A socket can be used to connect Java’s I/O system to other programs that may reside either on the local
There are two kinds of TCP sockets in Java. One is for servers, and the other is for clients. The `ServerSocket` class is designed to be a "listener," which waits for clients to connect before doing anything. Thus, `ServerSocket` is for servers. The `Socket` class is for clients. It is designed to connect to server sockets and initiate protocol exchanges. Because client sockets are the most commonly used by Java applications, they are examined here.

The creation of a `Socket` object implicitly establishes a connection between the client and server. There are no methods or constructors that explicitly expose the details of establishing that connection. Here are two constructors used to create client sockets:

<table>
<thead>
<tr>
<th>Constructor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>Socket(String hostName, int port)</code></td>
<td>Creates a socket connected to the named host and port.</td>
</tr>
<tr>
<td>Throws <code>UnknownHostException</code>, <code>IOException</code></td>
<td></td>
</tr>
<tr>
<td><code>Socket(InetAddress ipAddress, int port)</code></td>
<td>Creates a socket using a preexisting <code>InetAddress</code> object and a port.</td>
</tr>
</tbody>
</table>

A `Socket` defines several instance methods. For example, a `Socket` can be examined at any time for the address and port information associated with it, by use of the following methods:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>InetAddress getInetAddress()</code></td>
<td>Returns the <code>InetAddress</code> associated with the <code>Socket</code> object. It returns <code>null</code> if the socket is not connected.</td>
</tr>
<tr>
<td><code>int getPort()</code></td>
<td>Returns the remote port to which the invoking <code>Socket</code> object is connected. It returns 0 if the socket is not connected.</td>
</tr>
<tr>
<td><code>int getLocalPort()</code></td>
<td>Returns the local port to which the invoking <code>Socket</code> object is bound. It returns –1 if the socket is not bound.</td>
</tr>
</tbody>
</table>

You can gain access to the input and output streams associated with a `Socket` by use of the `getInputStream()` and `getOutputStream()` methods, as shown here. Each can throw an `IOException` if the socket has been invalidated by a loss of connection. These streams are used exactly like the I/O streams described in Chapter 21 to send and receive data.
```java
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>InputStream getInputStream()</code></td>
<td>Returns the <code>InputStream</code> associated with the invoking socket.</td>
</tr>
<tr>
<td><code>OutputStream getOutputStream()</code></td>
<td>Returns the <code>OutputStream</code> associated with the invoking socket.</td>
</tr>
</tbody>
</table>

Several other methods are available, including `connect()`, which allows you to specify a new connection; `isConnected()`, which returns true if the socket is connected to a server; `isBound()`, which returns true if the socket is bound to an address; and `isClosed()`, which returns true if the socket is closed. To close a socket, call `close()`. Closing a socket also closes the I/O streams associated with the socket.

Beginning with JDK 7, `Socket` also implements `AutoCloseable`, which means that you can use a `try-with-resources` block to manage a socket.

The following program provides a simple `Socket` example. It opens a connection to a "whois" port (port 43) on the InterNIC server, sends the command-line argument down the socket, and then prints the data that is returned. InterNIC will try to look up the argument as a registered Internet domain name, and then send back the IP address and contact information for that site.
// Demonstrate Sockets.
import java.net.*;
import java.io.*;

class Whois {
    public static void main(String args[]) throws Exception {
        int c;

        // Create a socket connected to internic.net, port 43.
        Socket s = new Socket("whois.internic.net", 43);

        // Obtain input and output streams.
        InputStream in = s.getInputStream();
        OutputStream out = s.getOutputStream();

        // Construct a request string.
        String str = (args.length == 0 ? "OraclePressBooks.com" : args[0]) + "\n";
        // Convert to bytes.
        byte buf[] = str.getBytes();

        // Send request.
        out.write(buf);

        // Read and display response.
        while ((c = in.read()) != -1) {
            System.out.print((char) c);
        }
        s.close();
    }
}

If, for example, you obtained information about OraclePressBooks.com, you’d get something similar to the following:
Here is how the program works. First, a Socket is constructed that specifies the host name "whois.internic.net" and the port number 43. Internic.net is the InterNIC web site that handles whois requests. Port 43 is the whois port. Next, both input and output streams are opened on the socket. Then, a string is constructed that contains the name of the web site you want to obtain information about. In this case, if no web site is specified on the command line, then "OraclePressBooks.com" is used. The string is converted into a byte array and then sent out of the socket. The response is read by inputting from the socket, and the results are displayed. Finally, the socket is closed, which also closes the I/O streams.

In the preceding example, the socket was closed manually by calling close( ). Beginning with JDK 7, you can use a try-with-resources block to automatically close the socket. For example, here is another way to write the main( ) method of the previous program:
In this version, the socket is automatically closed when the `try` block ends.

So the examples will work with earlier versions of Java and to clearly illustrate when a network resource can be closed, subsequent examples will continue to call `close()` explicitly. However, in your own code, you should consider using automatic resource management since it offers a more streamlined approach. One other point:
In this version, exceptions are still thrown out of `main()`, but they could be handled by adding `catch` clauses to the end of the `try-with-resources` block.

NOTE For simplicity, the examples in this chapter simply throw all exceptions out of `main()`. This allows the logic of the network code to be clearly illustrated. However, in real-world code, you will normally need to handle the exceptions in an appropriate way.
The preceding example was rather obscure because the modern Internet is not about the older protocols such as whois, finger, and FTP. It is about WWW, the World Wide Web. The Web is a loose collection of higher-level protocols and file formats, all unified in a web browser. One of the most important aspects of the Web is that Tim Berners-Lee devised a scalable way to locate all of the resources of the Net. Once you can reliably name anything and everything, it becomes a very powerful paradigm. The Uniform Resource Locator (URL) does exactly that.

The URL provides a reasonably intelligible form to uniquely identify or address information on the Internet. URLs are ubiquitous; every browser uses them to identify information on the Web. Within Java’s network class library, the URL class provides a simple, concise API to access information across the Internet using URLs. All URLs share the same basic format, although some variation is allowed. Here are two examples: http://www.HerbSchildt.com/ and http://www.HerbSchildt.com:80/index.htm. A URL specification is based on four components. The first is the protocol to use, separated from the rest of the locator by a colon (:). Common protocols are HTTP, FTP, gopher, and file, although these days almost everything is being done via HTTP (in fact, most browsers will proceed correctly if you leave off the "http://" from your URL specification). The second component is the host name or IP address of the host to use; this is delimited on the left by double slashes (//) and on the right by a slash (/) or optionally a colon (:). The third component, the port number, is an optional parameter, delimited on the left from the host name by a colon (:) and on the right by a slash (/). (It defaults to port 80, the predefined HTTP port; thus, ":80" is redundant.) The fourth part is the actual file path. Most HTTP servers will append a file named index.html or index.htm to URLs that refer directly to a directory resource. Thus, http://www.HerbSchildt.com/ is the same as http://www.HerbSchildt.com/index.htm.

Java’s URL class has several constructors; each can throw a MalformedURLException. One commonly used form specifies the URL with a string that is identical to what you see displayed in a browser:

```java
URL(String urlSpecifier) throws MalformedURLException
```

The next two forms of the constructor allow you to break up the URL into its component parts:

```java
URL(String protocolName, String hostName, int port, String path) throws MalformedURLException
URL(String protocolName, String hostName, String path) throws MalformedURLEexception
```

Another frequently used constructor allows you to use an existing URL as a
reference context and then create a new URL from that context. Although this sounds a little contorted, it’s really quite easy and useful.

URL(URL urlObj, String urlSpecifier) throws MalformedURLException

The following example creates a URL to a page on HerbSchildt.com and then examines its properties:

```java
// Demonstrate URL.
import java.net.*;

class URLDemo {
    public static void main(String args[]) throws MalformedURLException {
        URL hp = new URL("http://www.HerbSchildt.com/WhatsNew");

        System.out.println("Protocol: " + hp.getProtocol());
        System.out.println("Port: " + hp.getPort());

        System.out.println("Host: " + hp.getHost());
        System.out.println("File: " + hp.getFile());
        System.out.println("Ext:" + hp.toExternalForm());
    }
}
```

When you run this, you will get the following output:

```
Protocol: http
Port: -1
Host: www.HerbSchildt.com
File: /WhatsNew
```

Notice that the port is –1; this means that a port was not explicitly set. Given a URL object, you can retrieve the data associated with it. To access the actual bits or content information of a URL, create a URLConnection object from it, using its openConnection() method, like this:

```java
urlc = url.openConnection()
```

openConnection() has the following general form:

```java
URLConnection openConnection() throws IOException
```

It returns a URLConnection object associated with the invoking URL object. Notice that it may throw an IOException.

**URLConnection**
URLConnection is a general-purpose class for accessing the attributes of a remote resource. Once you make a connection to a remote server, you can use URLConnection to inspect the properties of the remote object before actually transporting it locally. These attributes are exposed by the HTTP protocol specification and, as such, only make sense for URL objects that are using the HTTP protocol.

URLConnection defines several methods. Here is a sampling:
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>int getContentLength()</td>
<td>Returns the size in bytes of the content associated with the resource. If the length is unavailable, -1 is returned.</td>
</tr>
<tr>
<td>long getContentLengthLong()</td>
<td>Returns the size in bytes of the content associated with the resource. If the length is unavailable, -1 is returned.</td>
</tr>
<tr>
<td>String getContentType()</td>
<td>Returns the type of content found in the resource. This is the value of the content-type header field. Returns null if the content type is not available.</td>
</tr>
<tr>
<td>long getDate()</td>
<td>Returns the time and date of the response represented in terms of milliseconds since January 1, 1970 GMT.</td>
</tr>
<tr>
<td>long getExpiration()</td>
<td>Returns the expiration time and date of the resource represented in terms of milliseconds since January 1, 1970 GMT. Zero is returned if the expiration date is unavailable.</td>
</tr>
<tr>
<td>String getHeaderField(int idx)</td>
<td>Returns the value of the header field at index idx. (Header field indexes begin at 0.) Returns null if the value of idx exceeds the number of fields.</td>
</tr>
<tr>
<td>String getHeaderField(String fieldName)</td>
<td>Returns the value of header field whose name is specified by fieldName. Returns null if the specified name is not found.</td>
</tr>
<tr>
<td>String getHeaderFieldKey(int idx)</td>
<td>Returns the header field key at index idx. (Header field indexes begin at 0.) Returns null if the value of idx exceeds the number of fields.</td>
</tr>
<tr>
<td>Map&lt;String, List&lt;String&gt;&gt; getHeaderFields()</td>
<td>Returns a map that contains all of the header fields and values.</td>
</tr>
<tr>
<td>long getLastModified()</td>
<td>Returns the time and date, represented in terms of milliseconds since January 1, 1970 GMT, of the last modification of the resource. Zero is returned if the last-modified date is unavailable.</td>
</tr>
<tr>
<td>InputStream getInputStream() throws IOException</td>
<td>Returns an InputStream that is linked to the resource. This stream can be used to obtain the content of the resource.</td>
</tr>
</tbody>
</table>

Notice that URLConnection defines several methods that handle header information. A header consists of pairs of keys and values represented as strings. By
using `getHeaderField()` , you can obtain the value associated with a header key. By
calling `getHeaderFields()` , you can obtain a map that contains all of the headers.
Several standard header fields are available directly through methods such as
`getDate()` and `getContentType()` .

The following example creates a `URLConnection` using the `openConnection()` method of a `URL` object and then uses it to examine the document’s properties and content:

```java
// Demonstrate URLConnection.
import java.net.*;
import java.io.*;
import java.util.Date;

class UCDemo {
    public static void main(String args[]) throws Exception {
        int c;
        URL hp = new URL("http://www.internic.net");
        URLConnection hpCon = hp.openConnection();

        // get date
        long d = hpCon.getDate();
        if (d == 0)
            System.out.println("No date information.");
        else
            System.out.println("Date: " + new Date(d));

        // get content type
        System.out.println("Content-Type: " + hpCon.getContentType());

        // get expiration date
        d = hpCon.getExpiration();
        if (d == 0)
            System.out.println("No expiration information.");
        else
            System.out.println("Expires: " + new Date(d));
    }
}
```
The program establishes an HTTP connection to www.internic.net over port 80. It then displays several header values and retrieves the content. You might find it interesting to try this example, observing the results, and then for comparison purposes try different web sites of your own choosing.

### HttpURLConnection

Java provides a subclass of URLConnection that provides support for HTTP connections. This class is called HttpURLConnection. You obtain an HttpURLConnection in the same way just shown, by calling openConnection() on a URL object, but you must cast the result to HttpURLConnection. (Of course, you must make sure that you are actually opening an HTTP connection.) Once you have obtained a reference to an HttpURLConnection object, you can use any of the methods inherited from URLConnection. You can also use any of the several
methods defined by `HttpURLConnection`. Here is a sampling:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>static boolean getFollowRedirects()</code></td>
<td>Returns <code>true</code> if redirects are automatically followed and <code>false</code> otherwise. This feature is on by default.</td>
</tr>
<tr>
<td><code>String getRequestMethod()</code></td>
<td>Returns a string representing how URL requests are made. The default is GET. Other options, such as POST, are available.</td>
</tr>
<tr>
<td><code>int getResponseCode()</code></td>
<td>Returns the HTTP response code. –1 is returned if no response code can be obtained. An <code>IOException</code> is thrown if the connection fails.</td>
</tr>
<tr>
<td><code>String getResponseMessage()</code></td>
<td>Returns the response message associated with the response code. Returns <code>null</code> if no message is available. An <code>IOException</code> is thrown if the connection fails.</td>
</tr>
<tr>
<td><code>static void setFollowRedirects(boolean how)</code></td>
<td>If <code>how</code> is <code>true</code>, then redirects are automatically followed. If <code>how</code> is <code>false</code>, redirects are not automatically followed. By default, redirects are automatically followed.</td>
</tr>
<tr>
<td><code>void setRequestMethod(String how)</code></td>
<td>Sets the method by which HTTP requests are made to that specified by <code>how</code>. The default method is GET, but other options, such as POST, are available. If <code>how</code> is invalid, a <code>ProtocolException</code> is thrown.</td>
</tr>
</tbody>
</table>

The following program demonstrates `HttpURLConnection`. It first establishes a connection to `www.google.com`. Then it displays the request method, the response code, and the response message. Finally, it displays the keys and values in the response header.
// Demonstrate HttpURLConnection.
import java.net.*;
import java.io.*;
import java.util.*;

class HttpURLConnectionDemo
{

    public static void main(String args[]) throws Exception {
        URL hp = new URL("http://www.google.com");

        HttpURLConnection hpCon = (HttpURLConnection) hp.openConnection();

        // Display request method.
        System.out.println("Request method is " +
                           hpCon.getMethod());

        // Display response code.
        System.out.println("Response code is " +
                           hpCon.getResponseCode());

        // Display response message.
        System.out.println("Response Message is " +
                           hpCon.getResponseMessage());

        // Get a list of the header fields and a set
        // of the header keys.
        Map<String, List<String>> hdrMap = hpCon.getHeaderFields();
        Set<String> hdrField = hdrMap.keySet();

        System.out.println("\nHere is the header:");

        // Display all header keys and values.
        for(String k : hdrField) {
            System.out.println("Key: " + k +
                                " Value: " + hdrMap.get(k));
        }
    }
}

The output produced by the program is shown here. (Of course, the exact response returned by www.google.com will vary over time.)
Request method is GET
Response code is 200
Response Message is OK

Here is the header:
Key: Transfer-Encoding Value: [chunked]
Key: null Value: [HTTP/1.1 200 OK]
Key: Server Value: [gws]
Key: P3P Value: [CP="This is not a P3P policy! See https://www.google.com/support/accounts/answer/151657?hl=en for more info."]
Key: Date Value: [Sat, 20 Aug 2016 15:27:15 GMT]
Key: Accept-Ranges Value: [none]
Key: X-Frame-Options Value: [SAMEORIGIN]
Key: Cache-Control Value: [private, max-age=0]
Key: Vary Value: [Accept-Encoding]
Key: Set-Cookie Value: [NID=84=RBHU6Qgm_YvBSBDRKRSa4H7rMplbqyXPEBMqYHE5 az51YAikuHi3ltd3qmjRdEKtP4DXxIGhhgrSPnJkvnZk7uvaT6puRBbMl1gLdvsRBmTHP9 ejcwmi9KQ0t9IZs81Eokwd1yw6r10ko; expires=Sun, 19-Feb-2017 15:27:15 GMT; path=/; domain=.google.com; HttpOnly]
Key: Expires Value: [-1]
Key: X-XSS-Protection Value: [1; mode=block]
Key: Content-Type Value: [text/html; charset=ISO-8859-1]

Notice how the header keys and values are displayed. First, a map of the header keys and values is obtained by calling `getHeaderFields()` (which is inherited from `URLConnection`). Next, a set of the header keys is retrieved by calling `keySet()` on the map. Then, the key set is cycled through by using a for-each style `for` loop. The value associated with each key is obtained by calling `get()` on the map.

The URI Class

The URI class encapsulates a Uniform Resource Identifier (URI). URIs are similar to URLs. In fact, URLs constitute a subset of URIs. A URI represents a standard way to identify a resource. A URL also describes how to access the resource.

Cookies

The java.net package includes classes and interfaces that help manage cookies and can be used to create a stateful (as opposed to stateless) HTTP session. The classes are CookieHandler, CookieManager, and HttpCookie. The interfaces are CookiePolicy and CookieStore. The creation of a stateful HTTP session is beyond the scope of this book.
TCP/IP Server Sockets

As mentioned earlier, Java has a different socket class that must be used for creating server applications. The `ServerSocket` class is used to create servers that listen for either local or remote client programs to connect to them on published ports. `ServerSockets` are quite different from normal `Sockets`. When you create a `ServerSocket`, it will register itself with the system as having an interest in client connections. The constructors for `ServerSocket` reflect the port number that you want to accept connections on and, optionally, how long you want the queue for said port to be. The queue length tells the system how many client connections it can leave pending before it should simply refuse connections. The default is 50. The constructors might throw an `IOException` under adverse conditions. Here are three of its constructors:

<table>
<thead>
<tr>
<th>Constructor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>ServerSocket(int port)</code></td>
<td>Creates server socket on the specified port with a queue length of 50.</td>
</tr>
<tr>
<td><code>ServerSocket(int port, int maxQueue)</code></td>
<td>Creates a server socket on the specified port with a maximum queue length of <code>maxQueue</code>.</td>
</tr>
<tr>
<td><code>ServerSocket(int port, int maxQueue, InetAddress localAddress)</code></td>
<td>Creates a server socket on the specified port with a maximum queue length of <code>maxQueue</code>. On a multihomed host, <code>localAddress</code> specifies the IP address to which this socket binds.</td>
</tr>
</tbody>
</table>

`ServerSocket` has a method called `accept()`, which is a blocking call that will wait for a client to initiate communications and then return with a normal `Socket` that is then used for communication with the client.

Datagrams

TCP/IP-style networking is appropriate for most networking needs. It provides a serialized, predictable, reliable stream of packet data. This is not without its cost, however. TCP includes many complicated algorithms for dealing with congestion control on crowded networks, as well as pessimistic expectations about packet loss. This leads to a somewhat inefficient way to transport data. Datagrams provide an alternative.

Datagrams are bundles of information passed between machines. They are somewhat like a hard throw from a well-trained but blindfolded catcher to the third
baseman. Once the datagram has been released to its intended target, there is no assurance that it will arrive or even that someone will be there to catch it. Likewise, when the datagram is received, there is no assurance that it hasn’t been damaged in transit or that whoever sent it is still there to receive a response.

Java implements datagrams on top of the UDP protocol by using two classes: the DatagramPacket object is the data container, while the DatagramSocket is the mechanism used to send or receive the DatagramPackets. Each is examined here.

**DatagramSocket**

DatagramSocket defines four public constructors. They are shown here:

- DatagramSocket() throws SocketException
- DatagramSocket(int port) throws SocketException
- DatagramSocket(int port, InetAddress ipAddress) throws SocketException
- DatagramSocket(SocketAddress address) throws SocketException

The first creates a DatagramSocket bound to any unused port on the local computer. The second creates a DatagramSocket bound to the port specified by port. The third constructs a DatagramSocket bound to the specified port and InetAddress. The fourth constructs a DatagramSocket bound to the specified SocketAddress. SocketAddress is an abstract class that is implemented by the concrete class InetSocketAddress. InetSocketAddress encapsulates an IP address with a port number. All can throw a SocketException if an error occurs while creating the socket.

DatagramSocket defines many methods. Two of the most important are send() and receive(), which are shown here:

- void send(DatagramPacket packet) throws IOException
- void receive(DatagramPacket packet) throws IOException

The send() method sends a packet to the port specified by packet. The receive() method waits for a packet to be received and returns the result.

DatagramSocket also defines the close() method, which closes the socket. Beginning with JDK 7, DatagramSocket implements AutoCloseable, which means that a DatagramSocket can be managed by a try-with-resources block.

Other methods give you access to various attributes associated with a DatagramSocket. Here is a sampling:
DatagramPacket

DatagramPacket defines several constructors. Four are shown here:

- `DatagramPacket(byte data [], int size)`
- `DatagramPacket(byte data [], int offset, int size)`
- `DatagramPacket(byte data [], int size, InetAddress ipAddress, int port)`
- `DatagramPacket(byte data [], int offset, int size, InetAddress ipAddress, int port)`

The first constructor specifies a buffer that will receive data and the size of a packet. It is used for receiving data over a `DatagramSocket`. The second form allows you to specify an offset into the buffer at which data will be stored. The third form specifies a target address and port, which are used by a `DatagramSocket` to determine where the data in the packet will be sent. The fourth form transmits packets beginning at the specified offset into the data. Think of the first two forms as building an "in box," and the second two forms as stuffing and addressing an envelope.

DatagramPacket defines several methods, including those shown here, that give access to the address and port number of a packet, as well as the raw data and its length:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>InetAddress get InetAddress()</code></td>
<td>If the socket is connected, then the address is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td><code>int getLocalPort()</code></td>
<td>Returns the number of the local port.</td>
</tr>
<tr>
<td><code>int getPort()</code></td>
<td>Returns the number of the port connected to the socket. It returns -1 if the socket is not connected to a port.</td>
</tr>
<tr>
<td><code>boolean isBound()</code></td>
<td>Returns true if the socket is bound to an address. Returns false otherwise.</td>
</tr>
<tr>
<td><code>boolean isConnected()</code></td>
<td>Returns true if the socket is connected to a server. Returns false otherwise.</td>
</tr>
<tr>
<td><code>void setSoTimeout(int millis)</code> throws SocketException</td>
<td>Sets the time-out period to the number of milliseconds passed in millis.</td>
</tr>
</tbody>
</table>
### A Datagram Example

The following example implements a very simple networked communications client and server. Messages are typed into the window at the server and written across the network to the client side, where they are displayed.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>InetAddress getAddress()</td>
<td>Returns the address of the source (for datagrams being received) or destination (for datagrams being sent).</td>
</tr>
<tr>
<td>byte[] getData()</td>
<td>Returns the byte array of data contained in the datagram. Mostly used to retrieve data from the datagram after it has been received.</td>
</tr>
<tr>
<td>int getLength()</td>
<td>Returns the length of the valid data contained in the byte array that would be returned from the getData() method. This may not equal the length of the whole byte array.</td>
</tr>
<tr>
<td>int getOffset()</td>
<td>Returns the starting index of the data.</td>
</tr>
<tr>
<td>int getPort()</td>
<td>Returns the port number.</td>
</tr>
<tr>
<td>void setAddress(InetAddress ipAddress)</td>
<td>Sets the address to which a packet will be sent. The address is specified by ipAddress.</td>
</tr>
<tr>
<td>void setData(byte[] data)</td>
<td>Sets the data to data, the offset to zero, and the length to number of bytes in data.</td>
</tr>
<tr>
<td>void setData(byte[] data, int idx, int size)</td>
<td>Sets the data to data, the offset to idx, and the length to size.</td>
</tr>
<tr>
<td>void setLength(int size)</td>
<td>Sets the length of the packet to size.</td>
</tr>
<tr>
<td>void setPort(int port)</td>
<td>Sets the port to port.</td>
</tr>
</tbody>
</table>
/ Demonstrate datagrams.
import java.net.*;

class WriteServer {
    public static int serverPort = 998;
    public static int clientPort = 999;
    public static int buffer_size = 1024;
    public static DatagramSocket ds;
    public static byte buffer[] = new byte[buffer_size];

    public static void TheServer() throws Exception {
        int pos=0;
        while (true) {
            int c = System.in.read();
        }
    }
}
This sample program is restricted by the `DatagramSocket` constructor to running between two ports on the local machine. To use the program, run

```
java WriteServer
```

in one window; this will be the client. Then run

```
java WriteServer
```

in another window; this will be the server.
java WriteServer 1

This will be the server. Anything that is typed in the server window will be sent to the client window after a newline is received.

**NOTE** The use of datagrams may not be allowed on your computer. (For example, a firewall may prevent their use.) If this is the case, the preceding example cannot be used. Also, the port numbers used in the program work on the author's system, but may have to be adjusted for your environment.
This chapter examines an important aspect of Java: the event. Event handling is fundamental to Java programming because it is integral to the creation of many kinds of applications. For example, any program that uses a graphical user interface, such as a Java application written for Windows, is event driven. Thus, you cannot write these types of programs without a solid command of event handling. Events are supported by a number of packages, including `java.util`, `java.awt`, and `java.awt.event`. Beginning with JDK 9, `java.awt` and `java.awt.event` are part of the `java.desktop` module, and `java.util` is part of the `java.base` module.

Most events to which your program will respond are generated when the user interacts with a GUI-based program. These are the types of events examined in this chapter. They are passed to your program in a variety of ways, with the specific method dependent upon the actual event. There are several types of events, including those generated by the mouse, the keyboard, and various GUI controls, such as a push button, scroll bar, or check box.

This chapter begins with an overview of Java’s event handling mechanism. It then examines a number of event classes and interfaces used by the Abstract Window Toolkit (AWT). The AWT was Java’s first GUI framework and it offers a simple way to present the basics of event handling. Next, the chapter develops several examples that demonstrate the fundamentals of event processing. This chapter also introduces key concepts related to GUI programming, and explains how to use adapter classes, inner classes, and anonymous inner classes to streamline event handling code. The examples provided in the remainder of this book make frequent use of these techniques.

NOTE This chapter focuses on events related to GUI-based programs. However, events are also occasionally used for purposes not directly related to GUI-based programs. In all cases, the same basic event handling techniques apply.

Two Event Handling Mechanisms

Before beginning our discussion of event handling, an important historical point must be made: The way in which events are handled changed significantly between the original version of Java (1.0) and all subsequent versions of Java, beginning with
version 1.1. Although the 1.0 method of event handling is still supported, it is not recommended for new programs. Also, many of the methods that support the old 1.0 event model have been deprecated. The modern approach is the way that events should be handled by all new programs and thus is the method employed by programs in this book.

The Delegation Event Model

The modern approach to handling events is based on the delegation event model, which defines standard and consistent mechanisms to generate and process events. Its concept is quite simple: a source generates an event and sends it to one or more listeners. In this scheme, the listener simply waits until it receives an event. Once an event is received, the listener processes the event and then returns. The advantage of this design is that the application logic that processes events is cleanly separated from the user interface logic that generates those events. A user interface element is able to “delegate” the processing of an event to a separate piece of code.

In the delegation event model, listeners must register with a source in order to receive an event notification. This provides an important benefit: notifications are sent only to listeners that want to receive them. This is a more efficient way to handle events than the design used by the original Java 1.0 approach. Previously, an event was propagated up the containment hierarchy until it was handled by a component. This required components to receive events that they did not process, and it wasted valuable time. The delegation event model eliminates this overhead.

The following sections define events and describe the roles of sources and listeners.

Events

In the delegation model, an event is an object that describes a state change in a source. Among other causes, an event can be generated as a consequence of a person interacting with the elements in a graphical user interface. Some of the activities that cause events to be generated are pressing a button, entering a character via the keyboard, selecting an item in a list, and clicking the mouse. Many other user operations could also be cited as examples.

Events may also occur that are not directly caused by interactions with a user interface. For example, an event may be generated when a timer expires, a counter exceeds a value, a software or hardware failure occurs, or an operation is completed. You are free to define events that are appropriate for your application.
Event Sources

A *source* is an object that generates an event. This occurs when the internal state of that object changes in some way. Sources may generate more than one type of event.

A source must register listeners in order for the listeners to receive notifications about a specific type of event. Each type of event has its own registration method. Here is the general form:

```
public void addTypeListener (TypeListener el)
```

Here, *Type* is the name of the event, and *el* is a reference to the event listener. For example, the method that registers a keyboard event listener is called `addKeyListener()`. The method that registers a mouse motion listener is called `addMouseMotionListener()`. When an event occurs, all registered listeners are notified and receive a copy of the event object. This is known as *multicasting* the event. In all cases, notifications are sent only to listeners that register to receive them.

Some sources may allow only one listener to register. The general form of such a method is this:

```
public void addTypeListener (TypeListener el) throws java.util.TooManyListenersException
```

Here, *Type* is the name of the event, and *el* is a reference to the event listener. When such an event occurs, the registered listener is notified. This is known as *unicasting* the event.

A source must also provide a method that allows a listener to unregister an interest in a specific type of event. The general form of such a method is this:

```
public void removeTypeListener (TypeListener el)
```

Here, *Type* is the name of the event, and *el* is a reference to the event listener. For example, to remove a keyboard listener, you would call `removeKeyListener()`. The methods that add or remove listeners are provided by the source that generates events. For example, `Component`, which is a top-level class defined by the AWT, provides methods to add and remove keyboard and mouse event listeners.

Event Listeners

A *listener* is an object that is notified when an event occurs. It has two major requirements. First, it must have been registered with one or more sources to receive
notifications about specific types of events. Second, it must implement methods to receive and process these notifications. In other words, the listener must supply the event handlers.

The methods that receive and process events are defined in a set of interfaces, such as those found in `java.awt.event`. For example, the `MouseMotionListener` interface defines two methods to receive notifications when the mouse is dragged or moved. Any object may handle one or both of these events if it provides an implementation of this interface. Other listener interfaces are discussed later in this and other chapters.

Here is one more key point about events: An event handler must return quickly. For the most part, a GUI program should not enter a “mode” of operation in which it maintains control for an extended period. Instead, it must perform specific actions in response to events and then return control to the run-time system. Failure to do this can cause your program to appear sluggish or even non-responsive. If your program needs to perform a repetitive task, such as scrolling a banner, it must do so by starting a separate thread. In short, when your program receives an event, it must process it immediately, and then return.

**Event Classes**

The classes that represent events are at the core of Java’s event handling mechanism. Thus, a discussion of event handling must begin with the event classes. It is important to understand, however, that Java defines several types of events and that not all event classes can be discussed in this chapter. Arguably, the most widely used events at the time of this writing are those defined by the AWT and those defined by Swing. This chapter focuses on the AWT events. (Most of these events also apply to Swing.) Several Swing-specific events are described in Chapter 31, when Swing is covered.

At the root of the Java event class hierarchy is `EventObject`, which is in `java.util`. It is the superclass for all events. Its one constructor is shown here:

```java
EventObject(Object src)
```

Here, `src` is the object that generates this event.

`EventObject` defines two methods: `getSource()` and `toString()`. The `getSource()` method returns the source of the event. Its general form is shown here:

```java
Object getSource()
```

As expected, `toString()` returns the string equivalent of the event.
The class **AWTEvent**, defined within the **java.awt** package, is a subclass of **EventObject**. It is the superclass (either directly or indirectly) of all AWT-based events used by the delegation event model. Its **getID()** method can be used to determine the type of the event. The signature of this method is shown here:

```java
int getID()
```

Additional details about **AWTEvent** are provided at the end of **Chapter 26**. At this point, it is important to know only that all of the other classes discussed in this section are subclasses of **AWTEvent**.

To summarize:

- **EventObject** is a superclass of all events.
- **AWTEvent** is a superclass of all AWT events that are handled by the delegation event model.

The package **java.awt.event** defines many types of events that are generated by various user interface elements. **Table 24-1** shows several commonly used event classes and provides a brief description of when they are generated. Commonly used constructors and methods in each class are described in the following sections.
<table>
<thead>
<tr>
<th>Event Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ActionEvent</td>
<td>Generated when a button is pressed, a list item is double-clicked, or a menu item is selected.</td>
</tr>
<tr>
<td>AdjustmentEvent</td>
<td>Generated when a scroll bar is manipulated.</td>
</tr>
<tr>
<td>ComponentEvent</td>
<td>Generated when a component is hidden, moved, resized, or becomes visible.</td>
</tr>
<tr>
<td>ContainerEvent</td>
<td>Generated when a component is added to or removed from a container.</td>
</tr>
<tr>
<td>FocusEvent</td>
<td>Generated when a component gains or loses keyboard focus.</td>
</tr>
<tr>
<td>InputEvent</td>
<td>Abstract superclass for all component input event classes.</td>
</tr>
<tr>
<td>ItemEvent</td>
<td>Generated when a check box or list item is clicked; also occurs when a choice selection is made or a checkable menu item is selected or deselected.</td>
</tr>
<tr>
<td>KeyEvent</td>
<td>Generated when input is received from the keyboard.</td>
</tr>
<tr>
<td>MouseEvent</td>
<td>Generated when the mouse is dragged, moved, clicked, pressed, or released; also generated when the mouse enters or exits a component.</td>
</tr>
<tr>
<td>MouseWheelEvent</td>
<td>Generated when the mouse wheel is moved.</td>
</tr>
<tr>
<td>TextEvent</td>
<td>Generated when the value of a text area or text field is changed.</td>
</tr>
<tr>
<td>WindowEvent</td>
<td>Generated when a window is activated, closed, deactivated, deiconified, iconified, opened, or quit.</td>
</tr>
</tbody>
</table>

Table 24-1  Commonly Used Event Classes in java.awt.event

The ActionEvent Class

An ActionEvent is generated when a button is pressed, a list item is double-clicked, or a menu item is selected. The ActionEvent class defines four integer constants that can be used to identify any modifiers associated with an action event: ALT_MASK, CTRL_MASK, META_MASK, and SHIFT_MASK. In addition, there is an integer constant, ACTION_PERFORMED, which can be used to identify action events.

ActionEvent has these three constructors:

```
ActionEvent(Object src, int type, String cmd)
ActionEvent(Object src, int type, String cmd, int modifiers)
ActionEvent(Object src, int type, String cmd, long when, int modifiers)
```

Here, src is a reference to the object that generated this event. The type of the event is specified by type, and its command string is cmd. The argument modifiers
indicates which modifier keys (alt, ctrl, meta, and/or shift) were pressed when the event was generated. The \textit{when} parameter specifies when the event occurred.

You can obtain the command name for the invoking \texttt{ActionEvent} object by using the \texttt{getActionCommand()} method, shown here:

\begin{verbatim}
String getActionCommand()
\end{verbatim}

For example, when a button is pressed, an action event is generated that has a command name equal to the label on that button.

The \texttt{getModifiers()} method returns a value that indicates which modifier keys (\texttt{ALT}, \texttt{CTRL}, \texttt{META}, and/or \texttt{SHIFT}) were pressed when the event was generated. Its form is shown here:

\begin{verbatim}
int getModifiers()
\end{verbatim}

The method \texttt{getWhen()} returns the time at which the event took place. This is called the event’s \textit{timestamp}. The \texttt{getWhen()} method is shown here:

\begin{verbatim}
long getWhen()
\end{verbatim}

\section*{The AdjustmentEvent Class}

An \texttt{AdjustmentEvent} is generated by a scroll bar. There are five types of adjustment events. The \texttt{AdjustmentEvent} class defines integer constants that can be used to identify them. The constants and their meanings are shown here:

<table>
<thead>
<tr>
<th>Constant</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLOCK_DECREMENT</td>
<td>The user clicked inside the scroll bar to decrease its value.</td>
</tr>
<tr>
<td>BLOCK_INCREMENT</td>
<td>The user clicked inside the scroll bar to increase its value.</td>
</tr>
<tr>
<td>TRACK</td>
<td>The slider was dragged.</td>
</tr>
<tr>
<td>UNIT_DECREMENT</td>
<td>The button at the end of the scroll bar was clicked to decrease its value.</td>
</tr>
<tr>
<td>UNIT_INCREMENT</td>
<td>The button at the end of the scroll bar was clicked to increase its value.</td>
</tr>
</tbody>
</table>

In addition, there is an integer constant, \texttt{ADJUSTMENT\_VALUE\_CHANGED}, that indicates that a change has occurred.

Here is one \texttt{AdjustmentEvent} constructor:

\begin{verbatim}
AdjustmentEvent(Adjustable src, int id, int type, int val)
\end{verbatim}
Here, src is a reference to the object that generated this event. The id specifies the event. The type of the adjustment is specified by type, and its associated value is val.

The getAdjustable() method returns the object that generated the event. Its form is shown here:

```java
Adjustable getAdjustable()
```

The type of the adjustment event may be obtained by the getAdjustmentType() method. It returns one of the constants defined by AdjustmentEvent. The general form is shown here:

```java
int getAdjustmentType()
```

The amount of the adjustment can be obtained from the getValue() method, shown here:

```java
int getValue()
```

For example, when a scroll bar is manipulated, this method returns the value represented by that change.

**The ComponentEvent Class**

A ComponentEvent is generated when the size, position, or visibility of a component is changed. There are four types of component events. The ComponentEvent class defines integer constants that can be used to identify them. The constants and their meanings are shown here:

<table>
<thead>
<tr>
<th>Constant</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPONENT_HIDDEN</td>
<td>The component was hidden.</td>
</tr>
<tr>
<td>COMPONENT_MOVED</td>
<td>The component was moved.</td>
</tr>
<tr>
<td>COMPONENT_RESIZED</td>
<td>The component was resized.</td>
</tr>
<tr>
<td>COMPONENT_SHOWN</td>
<td>The component became visible.</td>
</tr>
</tbody>
</table>

ComponentEvent has this constructor:

```java
ComponentEvent(Component src, int type)
```

Here, src is a reference to the object that generated this event. The type of the event is specified by type.

ComponentEvent is the superclass either directly or indirectly of
ContainerEvent, FocusEvent, KeyEvent, MouseEvent, and WindowEvent, among others.

The `getComponent()` method returns the component that generated the event. It is shown here:

```java
Component getComponent()
```

The **ContainerEvent Class**

A `ContainerEvent` is generated when a component is added to or removed from a container. There are two types of container events. The `ContainerEvent` class defines `int` constants that can be used to identify them: `COMPONENT_ADDED` and `COMPONENT_REMOVED`. They indicate that a component has been added to or removed from the container.

`ContainerEvent` is a subclass of `ComponentEvent` and has this constructor:

```java
ContainerEvent(Component src, int type, Component comp)
```

Here, `src` is a reference to the container that generated this event. The type of the event is specified by `type`, and the component that has been added to or removed from the container is `comp`.

You can obtain a reference to the container that generated this event by using the `getContainer()` method, shown here:

```java
Container getContainer()
```

The `getChild()` method returns a reference to the component that was added to or removed from the container. Its general form is shown here:

```java
Component getChild()
```

The **FocusEvent Class**

A `FocusEvent` is generated when a component gains or loses input focus. These events are identified by the integer constants `FOCUS_GAINED` and `FOCUS_LOST`.

`FocusEvent` is a subclass of `ComponentEvent` and has these constructors:

```java
FocusEvent(Component src, int type)
FocusEvent(Component src, int type, boolean temporaryFlag)
FocusEvent(Component src, int type, boolean temporaryFlag, Component other)
```
FocusEvent(Component src, int type, boolean temporaryFlag, Component other, FocusEvent.Cause what)

Here, src is a reference to the component that generated this event. The type of the event is specified by type. The argument temporaryFlag is set to true if the focus event is temporary. Otherwise, it is set to false. (A temporary focus event occurs as a result of another user interface operation. For example, assume that the focus is in a text field. If the user moves the mouse to adjust a scroll bar, the focus is temporarily lost.)

The other component involved in the focus change, called the opposite component, is passed in other. Therefore, if a FOCUS_GAINED event occurred, other will refer to the component that lost focus. Conversely, if a FOCUS_LOST event occurred, other will refer to the component that gains focus.

The fourth constructor was added by JDK 9. Its what parameter specifies why the event was generated. It is specified as a FocusEvent.Cause enumeration value that identifies the cause of the focus event. The FocusEvent.Cause enumeration was also added by JDK 9.

You can determine the other component by calling getOppositeComponent(), shown here:

Component getOppositeComponent( )

The opposite component is returned.

The isTemporary() method indicates if this focus change is temporary. Its form is shown here:

boolean isTemporary( )

The method returns true if the change is temporary. Otherwise, it returns false.

Beginning with JDK 9, you can obtain the cause of the event by calling getCause(), shown here:

final FocusEvent.Cause getCause( )

The cause is returned in the form of a FocusEvent.Cause enumeration value.

The InputEvent Class

The abstract class InputEvent is a subclass of ComponentEvent and is the superclass for component input events. Its subclasses are KeyEvent and
MouseEvent.

InputEvent defines several integer constants that represent any modifiers, such as the control key being pressed, that might be associated with the event. Originally, the InputEvent class defined the following eight values to represent the modifiers, and these modifiers may still be found in older legacy code:

<table>
<thead>
<tr>
<th>ALT_MASK</th>
<th>BUTTON2_MASK</th>
<th>META_MASK</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALT_GRAPH_MASK</td>
<td>BUTTON3_MASK</td>
<td>SHIFT_MASK</td>
</tr>
<tr>
<td>BUTTON1_MASK</td>
<td>CTRL_MASK</td>
<td></td>
</tr>
</tbody>
</table>

However, because of possible conflicts between the modifiers used by keyboard events and mouse events, and other issues, the following extended modifier values were added:

<table>
<thead>
<tr>
<th>ALT_DOWN_MASK</th>
<th>BUTTON2_DOWN_MASK</th>
<th>META_DOWN_MASK</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALT_GRAPH_DOWN_MASK</td>
<td>BUTTON3_DOWN_MASK</td>
<td>SHIFT_DOWN_MASK</td>
</tr>
<tr>
<td>BUTTON1_DOWN_MASK</td>
<td>CTRL_DOWN_MASK</td>
<td></td>
</tr>
</tbody>
</table>

When writing new code, you should use the new, extended modifiers rather than the original modifiers. Furthermore, the original modifiers have been deprecated by JDK 9.

To test if a modifier was pressed at the time an event is generated, use the isAltDown(), isAltGraphDown(), isControlDown(), isMetaDown(), and isShiftDown() methods. The forms of these methods are shown here:

```java
boolean isAltDown()
boolean isAltGraphDown()
boolean isControlDown()
boolean isMetaDown()
boolean isShiftDown()
```

It is possible to obtain a value that contains all of the original modifier flags by calling the getModifiers() method. It is shown here:

```java
int getModifiers()
```

Although you may still encounter getModifiers() in legacy code, it is important to point out that because the original modifier flags have been deprecated by JDK 9,
this method has also been deprecated by JDK 9. Instead, you should obtain the extended modifiers by calling `getModifiersEx()`, which is shown here:

```
int getModifiersEx()
```

The **ItemEvent** Class

An **ItemEvent** is generated when a check box or a list item is clicked or when a checkable menu item is selected or deselected. (Check boxes and list boxes are described later in this book.) There are two types of item events, which are identified by the following integer constants:

<table>
<thead>
<tr>
<th>DESELECTED</th>
<th>The user deselected an item.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SELECTED</td>
<td>The user selected an item.</td>
</tr>
</tbody>
</table>

In addition, **ItemEvent** defines the integer constant, **ITEM_STATE_CHANGED**, that signifies a change of state.

**ItemEvent** has this constructor:

```
ItemEvent(ItemSelectable src, int type, Object entry, int state)
```

Here, `src` is a reference to the component that generated this event. For example, this might be a list or choice element. The type of the event is specified by `type`. The specific item that generated the item event is passed in `entry`. The current state of that item is in `state`.

The `getItem()` method can be used to obtain a reference to the item that changed. Its signature is shown here:

```
Object getItem()
```

The `getItemSelectable()` method can be used to obtain a reference to the **ItemSelectable** object that generated an event. Its general form is shown here:

```
ItemSelectable getItemSelectable()
```

Lists and choices are examples of user interface elements that implement the **ItemSelectable** interface.

The `getStateChange()` method returns the state change (that is, **SELECTED** or **DESELECTED**) for the event. It is shown here:
int getStateChange( )

The KeyEvent Class

A KeyEvent is generated when keyboard input occurs. There are three types of key
events, which are identified by these integer constants: KEY_PRESSED,
KEY_RELEASED, and KEY_TYPED. The first two events are generated when
any key is pressed or released. The last event occurs only when a character is
generated. Remember, not all keypresses result in characters. For example, pressing
shift does not generate a character.

There are many other integer constants that are defined by KeyEvent. For
example, VK_0 through VK_9 and VK_A through VK_Z define the ASCII
equivalents of the numbers and letters. Here are some others:

<table>
<thead>
<tr>
<th>VK_ALT</th>
<th>VK_DOWN</th>
<th>VK_LEFT</th>
<th>VK_RIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_CANCEL</td>
<td>VK_ENTER</td>
<td>VK_PAGE_DOWN</td>
<td>VK_SHIFT</td>
</tr>
<tr>
<td>VK_CONTROL</td>
<td>VK_ESCAPE</td>
<td>VK_PAGE_UP</td>
<td>VK_UP</td>
</tr>
</tbody>
</table>

The VK constants specify virtual key codes and are independent of any modifiers,
such as control, shift, or alt.

KeyEvent is a subclass of InputEvent. Here is one of its constructors:

KeyEvent(Component src, int type, long when, int modifiers, int code, char ch)

Here, src is a reference to the component that generated the event. The type of the
event is specified by type. The system time at which the key was pressed is passed in
when. The modifiers argument indicates which modifiers were pressed when this key
event occurred. The virtual key code, such as VK_UP, VK_A, and so forth, is
passed in code. The character equivalent (if one exists) is passed in ch. If no valid
character exists, then ch contains CHAR_UNDEFINED. For KEY_TYPED events,
code will contain VK_UNDEFINED.

The KeyEvent class defines several methods, but probably the most commonly
used ones are getKeyChar(), which returns the character that was entered, and
gKeyCode(), which returns the key code. Their general forms are shown here:

    char getKeyChar( )
    int getKeyCode( )

If no valid character is available, then getKeyChar( ) returns
When a `KEY_TYPED` event occurs, `getKeyCode()` returns `VK_UNDEFINED`.

The MouseEvent Class

There are eight types of mouse events. The `MouseEvent` class defines the following integer constants that can be used to identify them:

<table>
<thead>
<tr>
<th>Mouse Event</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOUSE_CLICKED</td>
<td>The user clicked the mouse.</td>
</tr>
<tr>
<td>MOUSE_DRAGGED</td>
<td>The user dragged the mouse.</td>
</tr>
<tr>
<td>MOUSE_ENTERED</td>
<td>The mouse entered a component.</td>
</tr>
<tr>
<td>MOUSE_EXITED</td>
<td>The mouse exited from a component.</td>
</tr>
<tr>
<td>MOUSE_MOVED</td>
<td>The mouse moved.</td>
</tr>
<tr>
<td>MOUSE_PRESSED</td>
<td>The mouse was pressed.</td>
</tr>
<tr>
<td>MOUSE_RELEASED</td>
<td>The mouse was released.</td>
</tr>
<tr>
<td>MOUSE_WHEEL</td>
<td>The mouse wheel was moved.</td>
</tr>
</tbody>
</table>

`MouseEvent` is a subclass of `InputEvent`. Here is one of its constructors:

```java
MouseEvent(Component src, int type, long when, int modifiers, int x, int y, int clicks, boolean triggersPopup)
```

Here, `src` is a reference to the component that generated the event. The type of the event is specified by `type`. The system time at which the mouse event occurred is passed in `when`. The `modifiers` argument indicates which modifiers were pressed when a mouse event occurred. The coordinates of the mouse are passed in `x` and `y`. The click count is passed in `clicks`. The `triggersPopup` flag indicates if this event causes a pop-up menu to appear on this platform.

Two commonly used methods in this class are `getX()` and `getY()`. These return the X and Y coordinates of the mouse within the component when the event occurred. Their forms are shown here:

```java
int getX()
int getY()
```

Alternatively, you can use the `getPoint()` method to obtain the coordinates of the mouse. It is shown here:

```java
Point getPoint()
```

It returns a `Point` object that contains the X,Y coordinates in its integer members: `x`
and y.

The **translatePoint()** method changes the location of the event. Its form is shown here:

```java
void translatePoint(int x, int y)
```

Here, the arguments x and y are added to the coordinates of the event.

The **getClickCount()** method obtains the number of mouse clicks for this event. Its signature is shown here:

```java
int getClickCount()
```

The **isPopupTrigger()** method tests if this event causes a pop-up menu to appear on this platform. Its form is shown here:

```java
boolean isPopupTrigger()
```

Also available is the **getButton()** method, shown here:

```java
int getButton()
```

It returns a value that represents the button that caused the event. For most cases, the return value will be one of these constants defined by **MouseEvent**:

<table>
<thead>
<tr>
<th>NOBUTTON</th>
<th>BUTTON1</th>
<th>BUTTON2</th>
<th>BUTTON3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The **NOBUTTON** value indicates that no button was pressed or released.

Also available are three methods that obtain the coordinates of the mouse relative to the screen rather than the component. They are shown here:

```java
Point getLocationOnScreen()
int getXOnScreen()
int getYOnScreen()
```

The **getLocationOnScreen()** method returns a **Point** object that contains both the X and Y coordinate. The other two methods return the indicated coordinate.

**The MouseWheelEvent Class**

The **MouseWheelEvent** class encapsulates a mouse wheel event. It is a subclass of **MouseEvent**. Not all mice have wheels. If a mouse has a wheel, it is typically located between the left and right buttons. Mouse wheels are used for scrolling.
**MouseWheelEvent** defines these two integer constants:

<table>
<thead>
<tr>
<th>Const</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHEEL_BLOCK_SCROLL</td>
<td>A page-up or page-down scroll event occurred.</td>
</tr>
<tr>
<td>WHEEL_UNIT_SCROLL</td>
<td>A line-up or line-down scroll event occurred.</td>
</tr>
</tbody>
</table>

Here is one of the constructors defined by **MouseWheelEvent**:

```java
MouseWheelEvent(Component src, int type, long when, int modifiers,
                  int x, int y, int clicks, boolean triggersPopup,
                  int scrollHow, int amount, int count)
```

Here, `src` is a reference to the object that generated the event. The type of the event is specified by `type`. The system time at which the mouse event occurred is passed in `when`. The `modifiers` argument indicates which modifiers were pressed when the event occurred. The coordinates of the mouse are passed in `x` and `y`. The number of clicks is passed in `clicks`. The `triggersPopup` flag indicates if this event causes a pop-up menu to appear on this platform. The `scrollHow` value must be either `WHEEL_UNIT_SCROLL` or `WHEEL_BLOCK_SCROLL`. The number of units to scroll is passed in `amount`. The `count` parameter indicates the number of rotational units that the wheel moved.

**MouseWheelEvent** defines methods that give you access to the wheel event. To obtain the number of rotational units, call **getWheelRotation()**, shown here:

```java
int getWheelRotation( )
```

It returns the number of rotational units. If the value is positive, the wheel moved counterclockwise. If the value is negative, the wheel moved clockwise. Also available is a method called **getPreciseWheelRotation()**, which supports high-resolution wheels. It works like **getWheelRotation()**, but returns a **double**.

To obtain the type of scroll, call **getScrollType()**, shown next:

```java
int getScrollType( )
```

It returns either `WHEEL_UNIT_SCROLL` or `WHEEL_BLOCK_SCROLL`. If the scroll type is `WHEEL_UNIT_SCROLL`, you can obtain the number of units to scroll by calling **getScrollAmount()**. It is shown here:

```java
int getScrollAmount( )
```

**The TextEvent Class**
Instances of this class describe text events. These are generated by text fields and text areas when characters are entered by a user or program. **TextEvent** defines the integer constant **TEXT_VALUE_CHANGED**.

The one constructor for this class is shown here:

\[
\text{TextEvent(Object } src, \text{ int type)}
\]

Here, \( src \) is a reference to the object that generated this event. The type of the event is specified by \( type \).

The **TextEvent** object does not include the characters currently in the text component that generated the event. Instead, your program must use other methods associated with the text component to retrieve that information. This operation differs from other event objects discussed in this section. Think of a text event notification as a signal to a listener that it should retrieve information from a specific text component.

### The WindowEvent Class

There are ten types of window events. The **WindowEvent** class defines integer constants that can be used to identify them. The constants and their meanings are shown here:

<table>
<thead>
<tr>
<th>WINDOW_ACTIVATED</th>
<th>The window was activated.</th>
</tr>
</thead>
<tbody>
<tr>
<td>WINDOW_CLOSED</td>
<td>The window has been closed.</td>
</tr>
<tr>
<td>WINDOW_CLOSING</td>
<td>The user requested that the window be closed.</td>
</tr>
<tr>
<td>WINDOW_DEACTIVATED</td>
<td>The window was deactivated.</td>
</tr>
<tr>
<td>WINDOW_DEICONIFIED</td>
<td>The window was deiconified.</td>
</tr>
<tr>
<td>WINDOW_GAINED_FOCUS</td>
<td>The window gained input focus.</td>
</tr>
<tr>
<td>WINDOW_ICONIFIED</td>
<td>The window was iconified.</td>
</tr>
<tr>
<td>WINDOW_LOST_FOCUS</td>
<td>The window lost input focus.</td>
</tr>
<tr>
<td>WINDOW_OPENED</td>
<td>The window was opened.</td>
</tr>
<tr>
<td>WINDOW_STATE_CHANGED</td>
<td>The state of the window changed.</td>
</tr>
</tbody>
</table>

**WindowEvent** is a subclass of **ComponentEvent**. It defines several constructors. The first is

\[
\text{WindowEvent(Window } src, \text{ int type)}
\]
Here, *src* is a reference to the object that generated this event. The type of the event is *type*.

The next three constructors offer more detailed control:

```java
WindowEvent(Window src, int type, Window other)
WindowEvent(Window src, int type, int fromState, int toState)
WindowEvent(Window src, int type, Window other, int fromState, int toState)
```

Here, *other* specifies the opposite window when a focus or activation event occurs. The *fromState* specifies the prior state of the window, and *toState* specifies the new state that the window will have when a window state change occurs.

A commonly used method in this class is `getWindow()`. It returns the `Window` object that generated the event. Its general form is shown here:

```java
Window getWindow()
```

*WindowEvent* also defines methods that return the opposite window (when a focus or activation event has occurred), the previous window state, and the current window state. These methods are shown here:

```java
Window getOppositeWindow()
int getOldState()
int getNewState()
```

**Sources of Events**

Table 24-2 lists some of the user interface components that can generate the events described in the previous section. In addition to these graphical user interface elements, any class derived from `Component`, such as `Frame`, can generate events. For example, you can receive key and mouse events from an instance of `Frame`. In this chapter, we will be handling only mouse and keyboard events, but subsequent chapters will be handling events from a variety of sources.
As explained, the delegation event model has two parts: sources and listeners. As it relates to this chapter, listeners are created by implementing one or more of the interfaces defined by the `java.awt.event` package. When an event occurs, the event source invokes the appropriate method defined by the listener and provides an event object as its argument. 

### Table 24-3

<table>
<thead>
<tr>
<th>Event Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Button</td>
<td>Generates action events when the button is pressed.</td>
</tr>
<tr>
<td>Check box</td>
<td>Generates item events when the check box is selected or deselected.</td>
</tr>
<tr>
<td>Choice</td>
<td>Generates item events when the choice is changed.</td>
</tr>
<tr>
<td>List</td>
<td>Generates action events when an item is double-clicked; generates item events when an item is selected or deselected.</td>
</tr>
<tr>
<td>Menu item</td>
<td>Generates action events when a menu item is selected; generates item events when a checkable menu item is selected or deselected.</td>
</tr>
<tr>
<td>Scroll bar</td>
<td>Generates adjustment events when the scroll bar is manipulated.</td>
</tr>
<tr>
<td>Text components</td>
<td>Generates text events when the user enters a character.</td>
</tr>
<tr>
<td>Window</td>
<td>Generates window events when a window is activated, closed, deactivated, deiconified, iconified, opened, or quit.</td>
</tr>
</tbody>
</table>

**Event Listener Interfaces**

As explained, the delegation event model has two parts: sources and listeners. As it relates to this chapter, listeners are created by implementing one or more of the interfaces defined by the `java.awt.event` package. When an event occurs, the event source invokes the appropriate method defined by the listener and provides an event object as its argument. **Table 24-3** lists several commonly used listener interfaces and provides a brief description of the methods that they define. The following sections examine the specific methods that are contained in each interface.
Table 24-3  Commonly Used Event Listener Interfaces

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ActionListener</td>
<td>Defines one method to receive action events.</td>
</tr>
<tr>
<td>AdjustmentListener</td>
<td>Defines one method to receive adjustment events.</td>
</tr>
<tr>
<td>ComponentListener</td>
<td>Defines four methods to recognize when a component is hidden, moved, resized, or shown.</td>
</tr>
<tr>
<td>ContainerListener</td>
<td>Defines two methods to recognize when a component is added to or removed from a container.</td>
</tr>
<tr>
<td>FocusListener</td>
<td>Defines two methods to recognize when a component gains or loses keyboard focus.</td>
</tr>
<tr>
<td>ItemListener</td>
<td>Defines one method to recognize when the state of an item changes.</td>
</tr>
<tr>
<td>KeyListener</td>
<td>Defines three methods to recognize when a key is pressed, released, or typed.</td>
</tr>
<tr>
<td>MouseListener</td>
<td>Defines five methods to recognize when the mouse is clicked, enters a component, exits a component, is pressed, or is released.</td>
</tr>
<tr>
<td>MouseMotionListener</td>
<td>Defines two methods to recognize when the mouse is dragged or moved.</td>
</tr>
<tr>
<td>MouseWheelListener</td>
<td>Defines one method to recognize when the mouse wheel is moved.</td>
</tr>
<tr>
<td>TextListener</td>
<td>Defines one method to recognize when a text value changes.</td>
</tr>
<tr>
<td>WindowFocusListener</td>
<td>Defines two methods to recognize when a window gains or loses input focus.</td>
</tr>
<tr>
<td>WindowListener</td>
<td>Defines seven methods to recognize when a window is activated, closed, deactivated, deiconified, iconified, opened, or quit.</td>
</tr>
</tbody>
</table>

The ActionListener Interface

This interface defines the `actionPerformed()` method that is invoked when an action event occurs. Its general form is shown here:

```java
void actionPerformed(ActionEvent ae)
```

The AdjustmentListener Interface

This interface defines the `adjustmentValueChanged()` method that is invoked when an adjustment event occurs. Its general form is shown here:

```java
void adjustmentValueChanged(AdjustmentEvent ae)
```
The ComponentListener Interface
This interface defines four methods that are invoked when a component is resized, moved, shown, or hidden. Their general forms are shown here:

```java
void componentResized(ComponentEvent ce)
void componentMoved(ComponentEvent ce)
void componentShown(ComponentEvent ce)
void componentHidden(ComponentEvent ce)
```

The ContainerListener Interface
This interface contains two methods. When a component is added to a container, `componentAdded()` is invoked. When a component is removed from a container, `componentRemoved()` is invoked. Their general forms are shown here:

```java
void componentAdded(ContainerEvent ce)
void componentRemoved(ContainerEvent ce)
```

The FocusListener Interface
This interface defines two methods. When a component obtains keyboard focus, `focusGained()` is invoked. When a component loses keyboard focus, `focusLost()` is called. Their general forms are shown here:

```java
void focusGained(FocusEvent fe)
void focusLost(FocusEvent fe)
```

The ItemListener Interface
This interface defines the `itemStateChanged()` method that is invoked when the state of an item changes. Its general form is shown here:

```java
void itemStateChanged(ItemEvent ie)
```

The KeyListener Interface
This interface defines three methods. The `keyPressed()` and `keyReleased()` methods are invoked when a key is pressed and released, respectively. The `keyTyped()` method is invoked when a character has been entered.

For example, if a user presses and releases the a key, three events are generated in sequence: key pressed, typed, and released. If a user presses and releases the home
key, two key events are generated in sequence: key pressed and released.

The general forms of these methods are shown here:

```java
void keyPressed(KeyEvent ke)
void keyReleased(KeyEvent ke)
void keyTyped(KeyEvent ke)
```

**The MouseListener Interface**

This interface defines five methods. If the mouse is pressed and released at the same point, `mouseClicked()` is invoked. When the mouse enters a component, the `mouseEntered()` method is called. When it leaves, `mouseExited()` is called. The `mousePressed()` and `mouseReleased()` methods are invoked when the mouse is pressed and released, respectively.

The general forms of these methods are shown here:

```java
void mouseClicked(MouseEvent me)
void mouseEntered(MouseEvent me)
void mouseExited(MouseEvent me)
void mousePressed(MouseEvent me)
void mouseReleased(MouseEvent me)
```

**The MouseMotionListener Interface**

This interface defines two methods. The `mouseDragged()` method is called multiple times as the mouse is dragged. The `mouseMoved()` method is called multiple times as the mouse is moved. Their general forms are shown here:

```java
void mouseDragged(MouseEvent me)
void mouseMoved(MouseEvent me)
```

**The MouseWheelListener Interface**

This interface defines the `mouseWheelMoved()` method that is invoked when the mouse wheel is moved. Its general form is shown here:

```java
void mouseWheelMoved(MouseWheelEvent mwe)
```

**The TextListener Interface**
This interface defines the `textValueChanged()` method that is invoked when a change occurs in a text area or text field. Its general form is shown here:

```java
void textValueChanged(TextEvent te)
```

**The WindowFocusListener Interface**

This interface defines two methods: `windowGainedFocus()` and `windowLostFocus()`. These are called when a window gains or loses input focus. Their general forms are shown here:

```java
void windowGainedFocus(WindowEvent we)
void windowLostFocus(WindowEvent we)
```

**The WindowListener Interface**

This interface defines seven methods. The `windowActivated()` and `windowDeactivated()` methods are invoked when a window is activated or deactivated, respectively. If a window is iconified, the `windowIconified()` method is called. When a window is deiconified, the `windowDeiconified()` method is called. When a window is opened or closed, the `windowOpened()` or `windowClosed()` methods are called, respectively. The `windowClosing()` method is called when a window is being closed. The general forms of these methods are

```java
void windowActivated(WindowEvent we)
void windowClosed(WindowEvent we)
void windowClosing(WindowEvent we)
void windowDeactivated(WindowEvent we)
void windowDeiconified(WindowEvent we)
void windowIconified(WindowEvent we)
void windowOpened(WindowEvent we)
```

**Using the Delegation Event Model**

Now that you have learned the theory behind the delegation event model and have had an overview of its various components, it is time to see it in practice. Using the delegation event model is actually quite easy. Just follow these two steps:

1. Implement the appropriate interface in the listener so that it can receive the type of event desired.
2. Implement code to register and unregister (if necessary) the listener as a recipient for the event notifications.

Remember that a source may generate several types of events. Each event must be registered separately. Also, an object may register to receive several types of events, but it must implement all of the interfaces that are required to receive these events. In all cases, an event handler must return quickly. As explained earlier, an event handler must not retain control for an extended period of time.

To see how the delegation model works in practice, we will look at examples that handle two common event generators: the mouse and keyboard.

**Some Key AWT GUI Concepts**

To demonstrate the fundamentals of event handling, we will use several simple, GUI-based programs. As stated earlier, most events to which your program will respond will be generated by user interaction with GUI programs. Although the GUI programs shown in this chapter are very simple, it is still necessary to explain a few key concepts because GUI-based programs differ from the console-based programs found in many other parts of this book.

Before we begin, it is important to point out that Java supports three GUI frameworks: the AWT, Swing, and JavaFX. The AWT was Java’s first GUI framework, and for very limited GUI programs, it is the easiest to use. Swing, which is built on the foundation of the AWT, was Java’s second GUI framework and is still its most popular and widely used. JavaFX is the latest GUI framework, and it incorporates many advances in GUI design. All three frameworks are discussed later in this book. However, to demonstrate the fundamentals of event handling, AWT-based GUI programs are an appropriate choice and are used here.

There are four key AWT features used by the following programs. First, all create a top-level window by extending the `Frame` class. `Frame` defines what one would think of as a “normal” window. For example, it has minimize, maximize, and close boxes. It can be resized, covered, and redisplayed. Second, all override the `paint()` method to display output in the window. This method is called by the run-time system to display output in the window. For example, it is called when a window is first shown and after a window has been hidden and then uncovered. Third, when your program needs output displayed, it does not call `paint()` directly. Instead, you call `repaint()`. In essence, `repaint()` tells the AWT to call `paint()`. You will see how the process works in the examples that follow. Finally, when the top-level `Frame` window for an application is closed—for example, by clicking its close box—the program must explicitly exit, often through a call to `System.exit()`. Clicking the close box, by itself, does not cause the program to terminate. Therefore, it is
necessary for an AWT-based GUI program to handle a window-close event.

**Handling Mouse Events**

To handle mouse events, you must implement the `MouseListener` and the `MouseMotionListener` interfaces. (You may also want to implement `MouseWheelListener`, but we won’t be doing so, here.) The following program demonstrates the process. It displays the current coordinates of the mouse in the program’s window. Each time a button is pressed, the phrase “Button Down” is displayed at the location of the mouse pointer. Each time the button is released, the phrase “Button Released” is shown. If a button is clicked, a message stating this fact is displayed at the current mouse location.

As the mouse enters or exits the window, a message is displayed that indicates what happened. When dragging the mouse, a * is shown, which tracks with the mouse pointer as it is dragged. Notice that the two variables, `mouseX` and `mouseY`, store the location of the mouse when a mouse pressed, released, or dragged event occurs. These coordinates are then used by `paint( )` to display output at the point of these occurrences.

```java
// Demonstrate several mouse event handlers.
import java.awt.*;
import java.awt.event.*;

public class MouseEventsDemo extends Frame
    implements MouseListener, MouseMotionListener {

    String msg = "";
    int mouseX = 0, mouseY = 0; // coordinates of mouse

    public MouseEventsDemo() {
        addMouseListener(this);
        addMouseMotionListener(this);
        addWindowListener(new MyWindowAdapter());
    }
```
// Handle mouse clicked.
public void mouseClicked(MouseEvent me) {
    msg = msg + " -- click received";
    repaint();
}

// Handle mouse entered.
public void mouseEntered(MouseEvent me) {
    mouseX = 100;
    mouseY = 100;
    msg = "Mouse entered.";
    repaint();
}

// Handle mouse exited.
public void mouseExited(MouseEvent me) {
    mouseX = 100;
    mouseY = 100;
    msg = "Mouse exited.";
    repaint();
}
// Handle button pressed.
public void mousePressed(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "Button down";
    repaint();
}

// Handle button released.
public void mouseReleased(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "Button Released";
    repaint();
}

// Handle mouse dragged.
public void mouseDragged(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "*" + " mouse at " + mouseX + ", " + mouseY;
    repaint();
}

// Handle mouse moved.
public void mouseMoved(MouseEvent me) {
    msg = "Moving mouse at " + me.getX() + ", " + me.getY();
    repaint();
}
Let’s look closely at this example. First, notice that **MouseEventsDemo** extends **Frame**. Thus, it forms the top-level window for the application. Next, notice that it implements both the **MouseListener** and **MouseMotionListener** interfaces. These two interfaces contain methods that receive and process various types of mouse
events. Notice that `MouseEventsDemo` is both the source and the listener for these events. This works because `Frame` supplies the `addMouseListener()` and `addMouseMotionListener()` methods. Being both the source and the listener for events is not uncommon for simple GUI programs.

Inside the `MouseEventsDemo` constructor, the program registers itself as a listener for mouse events. This is done by calling `addMouseListener()` and `addMouseMotionListener()`. They are shown here:

```java
void addMouseListener(MouseListener ml)
void addMouseMotionListener(MouseMotionListener mml)
```

Here, `ml` is a reference to the object receiving mouse events, and `mml` is a reference to the object receiving mouse motion events. In this program, the same object is used for both. `MouseEventsDemo` then implements all of the methods defined by the `MouseListener` and `MouseMotionListener` interfaces. These are the event handlers for the various mouse events. Each method handles its event and then returns.

Notice that the `MouseEventsDemo` constructor also adds a `WindowListener`. This is needed to enable the program to respond to a window close event when the user clicks the close box. This listener uses an adapter class to implement the `WindowListener` interface. Adapter classes supply empty implementations of a listener interface, enabling you to override only the method or methods in which you are interested. They are described in detail later in this chapter, but one is used here to greatly simplify the code needed to close the program. In this case, the `windowClosing()` method is overridden. This method is called by the AWT when the window is closed. Here, it calls `System.exit()` to end the program.

Now notice the mouse event handlers. Each time a mouse event occurs, `msg` is assigned a string that describes what happened and then `repaint()` is called. In this case, `repaint()` ultimately causes the AWT to call `paint()` to display output. (This process is examined in greater detail in Chapter 25.) Notice that `paint()` has a parameter of type `Graphics`. This class describes the graphics context of the program. It is required for output. The program uses the `drawString()` method provided by `Graphics` to actually display a string in the window at the specified X, Y location. The form used in the program is shown here:

```java
void drawString(String message, int x, int y)
```

Here, `message` is the string to be output beginning at `x, y`. In a Java window, the upper-left corner is location 0,0. As mentioned, `mouseX` and `mouseY` keep track of the location of the mouse. These values are passed to `drawString()` as the location at which output is displayed.
Finally, the program is started by creating a **MouseEventsDemo** instance and then setting the size of the window, its title, and making the window visible. These features are described in greater detail in Chapter 25.

**Handling Keyboard Events**

To handle keyboard events, you use the same general architecture as that shown in the mouse event example in the preceding section. The difference, of course, is that you will be implementing the **KeyListener** interface.

Before looking at an example, it is useful to review how key events are generated. When a key is pressed, a **KEY_PRESSED** event is generated. This results in a call to the `keyPressed()` event handler. When the key is released, a **KEY_RELEASED** event is generated and the `keyReleased()` handler is executed. If a character is generated by the keystroke, then a **KEY_TYPED** event is sent and the `keyTyped()` handler is invoked. Thus, each time the user presses a key, at least two and often three events are generated. If all you care about are actual characters, then you can ignore the information passed by the key press and release events. However, if your program needs to handle special keys, such as the arrow or function keys, then it must watch for them through the `keyPressed()` handler.

The following program demonstrates keyboard input. It echoes keystrokes to the window and shows the pressed/released status of each key.
// Demonstrate the key event handlers.
import java.awt.*;
import java.awt.event.*;

public class SimpleKey extends Frame
  implements KeyListener {

  String msg = "";
  String keyState = "";

  public SimpleKey() {
    addKeyListener(this);
    addWindowListener(new MyWindowAdapter());
  }

  // Handle a key press.
  public void keyPressed(KeyEvent ke) {
    keyState = "Key Down";
    repaint();
  }

  // Handle a key release.
  public void keyReleased(KeyEvent ke) {
    keyState = "Key Up";
    repaint();
  }

  // Handle key typed.
  public void keyTyped(KeyEvent ke) {
    msg += ke.getKeyChar();
    repaint();
  }
}
If you want to handle the special keys, such as the arrow or function keys, you need to respond to them within the keyPressed() handler. They are not available through keyTyped(). To identify the keys, you use their virtual key codes. For example, the next program outputs the name of a few of the special keys:
/ Demonstrate some virtual key codes.
import java.awt.*;
import java.awt.event.*;

public class KeyEventsDemo extends Frame
    implements KeyListener {

    String msg = "";
    String keyState = "";

    public KeyEventsDemo() {
        addKeyListener(this);
        addWindowListener(new MyWindowAdapter());
    }

    // Handle a key press.
    public void keyPressed(KeyEvent ke) {
        keyState = "Key Down";
        int key = ke.getKeyCode();
        switch (key) {
            case KeyEvent.VK_F1:
                msg += "<F1>");
                break;
            case KeyEvent.VK_F2:
                msg += "<F2>");
                break;
            case KeyEvent.VK_F3:
                msg += "<F3>");
                break;
            case KeyEvent.VK_PAGE_DOWN:
                msg += "<PgDn>");
                break;
        }
    }
}
case KeyEvent.VK_PAGE_UP:
    msg += "<PgUp>";
    break;

case KeyEvent.VK_LEFT:
    msg += "<Left Arrow>";
    break;

case KeyEvent.VK_RIGHT:
    msg += "<Right Arrow>";
    break;

repaint();
}

// Handle a key release.
public void keyReleased(KeyEvent ke) {
    keyState = "Key Up";
    repaint();
}

// Handle key typed.
public void keyTyped(KeyEvent ke) {
    msg += ke.getKeyChar();
    repaint();
}
The procedures shown in the preceding keyboard and mouse event examples can be generalized to any type of event handling, including those events generated by controls. In later chapters, you will see many examples that handle other types of events, but they will all follow the same basic structure as the programs just described.

**Adapter Classes**

Java provides a special feature, called an *adapter class*, that can simplify the creation
of event handlers in certain situations. An adapter class provides an empty implementation of all methods in an event listener interface. Adapter classes are useful when you want to receive and process only some of the events that are handled by a particular event listener interface. You can define a new class to act as an event listener by extending one of the adapter classes and implementing only those events in which you are interested.

For example, the `MouseMotionAdapter` class has two methods, `mouseDragged()` and `mouseMoved()`, which are the methods defined by the `MouseMotionListener` interface. If you were interested in only mouse drag events, then you could simply extend `MouseMotionAdapter` and override `mouseDragged()`. The empty implementation of `mouseMoved()` would handle the mouse motion events for you.

Table 24-4 lists several commonly used adapter classes in `java.awt.event` and notes the interface that each implements.

<table>
<thead>
<tr>
<th>Adapter Class</th>
<th>Listener Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>ComponentAdapter</td>
<td>ComponentListener</td>
</tr>
<tr>
<td>ContainerAdapter</td>
<td>ContainerListener</td>
</tr>
<tr>
<td>FocusAdapter</td>
<td>FocusListener</td>
</tr>
<tr>
<td>KeyAdapter</td>
<td>KeyListener</td>
</tr>
<tr>
<td>MouseAdapter</td>
<td>MouseListener, MouseMotionListener, and MouseWheelListener</td>
</tr>
<tr>
<td>MouseMotionAdapter</td>
<td>MouseMotionListener</td>
</tr>
<tr>
<td>WindowAdapter</td>
<td>WindowListener, WindowFocusListener, and WindowStateListener</td>
</tr>
</tbody>
</table>

Table 24-4  Commonly Used Listener Interfaces Implemented by Adapter Classes

You have already seen one adapter class in action in the preceding examples: `WindowAdapter`. Recall that the `WindowListener` interface defines seven methods, but only one, `windowClosing()`, was needed by the programs. The use of the adapter prevented the need to provide empty implementations of the other unused methods, thus avoiding clutter in the examples. As you would expect, the other adapter classes can be employed in a similar fashion.

The following program provides another example of an adapter. It uses `MouseAdapter` to respond to mouse click and mouse drag events. As shown in Table 24-4, `MouseAdapter` implements all of the mouse listener interfaces. Thus, you can use it to handle all types of mouse events. Of course, you need override only
those methods that are used by your program. In the following example, 
MyMouseAdapter extends MouseAdapter and overrides the mouseClicked() and 
mouseDragged() methods. All other mouse events are silently ignored. Notice that 
the MyMouseAdapter constructor is passed a reference to the AdapterDemo 
instance. This reference is saved and then used to assign a string to msg and to 
invoke repaint() on the object that receives the event notification. As before, a 
WindowAdapter is used to handle a window closing event.

```java
// Demonstrate adapter classes.
import java.awt.*;
import java.awt.event.*;

public class AdapterDemo extends Frame {
    String msg = "";

    public AdapterDemo() {
        addMouseListener(new MyMouseAdapter(this));
        addMouseMotionListener(new MyMouseAdapter(this));
        addWindowListener(new MyWindowAdapter());
    }

    // Display the mouse information.
    public void paint(Graphics g) {
        g.drawString(msg, 20, 80);
    }

    public static void main(String[] args) {
        AdapterDemo appwin = new AdapterDemo();

        appwin.setSize(new Dimension(200, 150));
        appwin.setTitle("AdapterDemo");
        appwin.setVisible(true);
    }
}

// Handle only mouse click and drag events.
class MyMouseAdapter extends MouseAdapter {
    AdapterDemo adapterDemo;
```
As you can see by looking at the program, not having to implement all of the methods defined by the `MouseMotionListener`, `MouseListener`, and `MouseWheelListener` interfaces saves you a considerable amount of effort and prevents your code from becoming cluttered with empty methods. As an exercise, you might want to try rewriting one of the keyboard input examples shown earlier so that it uses a `KeyAdapter`.

**Inner Classes**

In Chapter 7, the basics of inner classes were explained. Here, you will see why they are important. Recall that an *inner class* is a class defined within another class, or even within an expression. This section illustrates how inner classes can be used to simplify the code when using event adapter classes.

To understand the benefit provided by inner classes, consider the program shown in the following listing. It *does not* use an inner class. Its goal is to display the string "Mouse Pressed" when the mouse is pressed. Similar to the approach used by the preceding example, a reference to the `MousePressedDemo` instance is passed to the

```java

As you can see by looking at the program, not having to implement all of the methods defined by the `MouseMotionListener`, `MouseListener`, and `MouseWheelListener` interfaces saves you a considerable amount of effort and prevents your code from becoming cluttered with empty methods. As an exercise, you might want to try rewriting one of the keyboard input examples shown earlier so that it uses a `KeyAdapter`.

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```java
```
MyMouseAdapter constructor and saved. This reference is used to assign a string to msg and invoke repaint() on the object that received the event.

// This program does NOT use an inner class.
import java.awt.*;
import java.awt.event.*;

public class MousePressedDemo extends Frame {
    String msg = "";
public MousePressedDemo() {
    addMouseListener(new MyMouseAdapter(this));
    addWindowListener(new MyWindowAdapter());
}

class MyMouseAdapter extends MouseAdapter {
    MousePressedDemo mousePressedDemo;

    public MyMouseAdapter(MousePressedDemo mousePressedDemo) {
        this.mousePressedDemo = mousePressedDemo;
    }

    public void mousePressed(MouseEvent me) {
        mousePressedDemo.msg = "Mouse Pressed.");
        mousePressedDemo.repaint();
    }
}

public void paint(Graphics g) {
    g.drawString(msg, 20, 100);
}

public static void main(String[] args) {
    MousePressedDemo appwin = new MousePressedDemo();

    appwin.setSize(new Dimension(200, 150));
    appwin.setTitle("MousePressedDemo");
    appwin.setVisible(true);
}

class MyWindowAdapter extends WindowAdapter {
    public void windowClosing(WindowEvent we) {
        System.exit(0);
    }
}

The following listing shows how the preceding program can be improved by using an inner class. Here, InnerClassDemo is the top-level class and MyMouseAdapter is an inner class. Because MyMouseAdapter is defined within the scope of InnerClassDemo, it has access to all of the variables and methods
within the scope of that class. Therefore, the `mousePressed()` method can call the `repaint()` method directly. It no longer needs to do this via a stored reference. The same applies to assigning a value to `msg`. Thus, it is no longer necessary to pass `MyMouseAdapter()` a reference to the invoking object. Also notice that `MyWindowAdapter` has been made into an inner class.

```java
// Inner class demo.
import java.awt.*;
import java.awt.event.*;
```
Anonymous Inner Classes

An anonymous inner class is one that is not assigned a name. This section illustrates how an anonymous inner class can facilitate the writing of event handlers. Consider the program shown in the following listing. As before, its goal is to display the string "Mouse Pressed" when the mouse is pressed.

```java
public class InnerClassDemo extends Frame {
    String msg = "";

    public InnerClassDemo() {
        addMouseListener(new MyMouseListener());
        addWindowListener(new MyWindowAdapter());
    }

    // Inner class to handle mouse pressed events.
    class MyMouseListener extends MouseAdapter {
        public void mousePressed(MouseEvent me) {
            msg = "Mouse Pressed.";
            repaint();
        }
    }

    // Inner class to handle window close events.
    class MyWindowAdapter extends WindowAdapter {
        public void windowClosing(WindowEvent we) {
            System.exit(0);
        }
    }

    public void paint(Graphics g) {
        g.drawString(msg, 20, 80);
    }

    public static void main(String[] args) {
        InnerClassDemo appwin = new InnerClassDemo();

        appwin.setSize(new Dimension(200, 150));
        appwin.setTitle("InnerClassDemo");
        appwin.setVisible(true);
    }
}
```
// Anonymous inner class demo.
import java.awt.*;
import java.awt.event.*;

public class AnonymousInnerClassDemo extends Frame {
    String msg = "";

    public AnonymousInnerClassDemo() {
        // Anonymous inner class to handle mouse pressed events.
        addMouseListener(new MouseAdapter() {
            public void mousePressed(MouseEvent me) {
                msg = "Mouse Pressed."
                repaint();
            }
        });

        // Anonymous inner class to handle window close events.
        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }

    public void paint(Graphics g) {
        g.drawString(msg, 20, 80);
    }

    public static void main(String[] args) {
        AnonymousInnerClassDemo appwin =
                new AnonymousInnerClassDemo();

        appwin.setSize(new Dimension(200, 150));
        appwin.setTitle("AnonymousInnerClassDemo");
        appwin.setVisible(true);
    }
}

There is one top-level class in this program: AnonymousInnerClassDemo. Its constructor calls the addMouseListener() method. Its argument is an expression that defines and instantiates an anonymous inner class. Let’s analyze this expression carefully.
The syntax `new MouseAdapter(){...}` indicates to the compiler that the code between the braces defines an anonymous inner class. Furthermore, that class extends `MouseAdapter`. This new class is not named, but it is automatically instantiated when this expression is executed. This syntax can be generalized and is the same when creating other anonymous classes, such as when an anonymous `WindowAdapter` is created by the program.

Because this anonymous inner class is defined within the scope of `AnonymousInnerClassDemo`, it has access to all of the variables and methods within the scope of that class. Therefore, it can call the `repaint()` method and access `msg` directly.

As just illustrated, both named and anonymous inner classes solve some annoying problems in a simple yet effective way. They also allow you to create more efficient code.
Introducing the AWT: Working with Windows, Graphics, and Text

The Abstract Window Toolkit (AWT) was Java’s first GUI framework, and it has been part of Java since version 1.0. It contains numerous classes and methods that allow you to create windows and simple controls. The AWT was introduced in Chapter 24, where it was used in several short examples that demonstrated event handling. This chapter begins a more detailed examination. Here, you will learn how to manage windows, work with fonts, output text, and utilize graphics. Chapter 26 describes various AWT controls, layout managers, and menus. It also explains further aspects of Java’s event handling mechanism. Chapter 27 introduces the AWT’s imaging subsystem.

It is important to state at the outset that you will seldom create GUIs based solely on the AWT because more powerful GUI frameworks (Swing and JavaFX) have been developed for Java. Despite this fact, the AWT remains an important part of Java. To understand why, consider the following.

At the time of this writing, the framework that is most widely used is Swing. Because Swing provides a richer, more flexible GUI framework than does the AWT, it is easy to jump to the conclusion that the AWT is no longer relevant—that it has been fully superseded by Swing. This assumption is, however, false. Instead, an understanding of the AWT is still important because the AWT underpins Swing, with many AWT classes being used either directly or indirectly by Swing. As a result, a solid knowledge of the AWT is still required to use Swing effectively.

Java’s newest GUI framework is JavaFX. It is anticipated that, at some point in the future, JavaFX will replace Swing as Java’s most popular GUI. Even when this occurs, however, much legacy code that relies on Swing (and thus, the AWT) will still need to be maintained for some time to come. Finally, for some types of small programs that make only minimal use of a GUI, using the AWT may still be appropriate. Therefore, even though the AWT constitutes Java’s oldest GUI framework, a basic working knowledge of its fundamentals is still important today.

One last point before beginning: The AWT is quite large and a full description would easily fill an entire book. Therefore, it is not possible to describe in detail every AWT class, method, or instance variable. However, this and the following chapters explain the basic techniques needed to use the AWT. From there, you will
be able to explore other parts of the AWT on your own. You will also be ready to move on to Swing.

**NOTE** If you have not yet read Chapter 24, please do so now. It provides an overview of event handling, which is used by many of the examples in this chapter.

**AWT Classes**

The AWT classes are contained in the `java.awt` package. It is one of Java’s largest packages. Fortunately, because it is logically organized in a top-down, hierarchical fashion, it is easier to understand and use than you might at first believe. Beginning with JDK 9, `java.awt` is part of the `java.desktop` module. Table 25-1 lists some of the many AWT classes.
<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWTEvent</td>
<td>Encapsulates AWT events.</td>
</tr>
<tr>
<td>AWTEventMulticaster</td>
<td>Dispatches events to multiple listeners.</td>
</tr>
<tr>
<td>BorderLayout</td>
<td>The border layout manager. Border layouts use five components: North, South, East, West, and Center.</td>
</tr>
<tr>
<td>Button</td>
<td>Creates a push button control.</td>
</tr>
<tr>
<td>Canvas</td>
<td>A blank, semantics-free window.</td>
</tr>
<tr>
<td>CardLayout</td>
<td>The card layout manager. Card layouts emulate index cards. Only the one on top is showing.</td>
</tr>
<tr>
<td>Checkbox</td>
<td>Creates a check box control.</td>
</tr>
<tr>
<td>CheckboxGroup</td>
<td>Creates a group of check box controls.</td>
</tr>
<tr>
<td>CheckboxMenuItem</td>
<td>Creates an on/off menu item.</td>
</tr>
<tr>
<td>Choice</td>
<td>Creates a pop-up list.</td>
</tr>
<tr>
<td>Color</td>
<td>Manages colors in a portable, platform-independent fashion.</td>
</tr>
<tr>
<td>Component</td>
<td>An abstract superclass for various AWT components.</td>
</tr>
<tr>
<td>Container</td>
<td>A subclass of Component that can hold other components.</td>
</tr>
<tr>
<td>Cursor</td>
<td>Encapsulates a bitmapped cursor.</td>
</tr>
<tr>
<td>Dialog</td>
<td>Creates a dialog window.</td>
</tr>
<tr>
<td>Dimension</td>
<td>Specifies the dimensions of an object. The width is stored in width, and the height is stored in height.</td>
</tr>
<tr>
<td>EventQueue</td>
<td>Queues events.</td>
</tr>
<tr>
<td>FileDialog</td>
<td>Creates a window from which a file can be selected.</td>
</tr>
<tr>
<td>Class</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>FlowLayout</td>
<td>The flow layout manager. Flow layout positions components left to right, top to bottom.</td>
</tr>
<tr>
<td>Font</td>
<td>Encapsulates a type font.</td>
</tr>
<tr>
<td>FontMetrics</td>
<td>Encapsulates various information related to a font. This information helps you display text in a window.</td>
</tr>
<tr>
<td>Frame</td>
<td>Creates a standard window that has a title bar, resize corners, and a menu bar.</td>
</tr>
<tr>
<td>Graphics</td>
<td>Encapsulates the graphics context. This context is used by the various output methods to display output in a window.</td>
</tr>
<tr>
<td>GraphicsDevice</td>
<td>Describes a graphics device such as a screen or printer.</td>
</tr>
<tr>
<td>GraphicsEnvironment</td>
<td>Describes the collection of available Font and GraphicsDevice objects.</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>Defines various constraints relating to the GridBagLayout class.</td>
</tr>
<tr>
<td>GridBagLayout</td>
<td>The grid bag layout manager. Grid bag layout displays components subject to the constraints specified by GridBagConstraints.</td>
</tr>
<tr>
<td>GridLayout</td>
<td>The grid layout manager. Grid layout displays components in a two-dimensional grid.</td>
</tr>
<tr>
<td>Image</td>
<td>Encapsulates graphical images.</td>
</tr>
<tr>
<td>Insets</td>
<td>Encapsulates the borders of a container.</td>
</tr>
<tr>
<td>Label</td>
<td>Creates a label that displays a string.</td>
</tr>
<tr>
<td>List</td>
<td>Creates a list from which the user can choose. Similar to the standard Windows list box.</td>
</tr>
<tr>
<td>MediaTracker</td>
<td>Manages media objects.</td>
</tr>
<tr>
<td>Menu</td>
<td>Creates a pull-down menu.</td>
</tr>
<tr>
<td>MenuBar</td>
<td>Creates a menu bar.</td>
</tr>
<tr>
<td>MenuComponent</td>
<td>An abstract class implemented by various menu classes.</td>
</tr>
<tr>
<td>MenuItem</td>
<td>Creates a menu item.</td>
</tr>
<tr>
<td>MenuShortcut</td>
<td>Encapsulates a keyboard shortcut for a menu item.</td>
</tr>
<tr>
<td>Panel</td>
<td>The simplest concrete subclass of Container.</td>
</tr>
<tr>
<td>Point</td>
<td>Encapsulates a Cartesian coordinate pair, stored in x and y.</td>
</tr>
<tr>
<td>Polygon</td>
<td>Encapsulates a polygon.</td>
</tr>
<tr>
<td>PopupMenu</td>
<td>Encapsulates a pop-up menu.</td>
</tr>
<tr>
<td>PrintJob</td>
<td>An abstract class that represents a print job.</td>
</tr>
<tr>
<td>Rectangle</td>
<td>Encapsulates a rectangle.</td>
</tr>
<tr>
<td>Robot</td>
<td>Supports automated testing of AWT-based applications.</td>
</tr>
<tr>
<td>Scrollbar</td>
<td>Creates a scroll bar control.</td>
</tr>
<tr>
<td>ScrollPane</td>
<td>A container that provides horizontal and/or vertical scroll bars for another component.</td>
</tr>
</tbody>
</table>
Although the basic structure of the AWT has been the same since Java 1.0, some of the original methods were deprecated and replaced by new ones. For backward-compatibility, Java still supports all the original 1.0 methods. However, because these methods are not for use with new code, this book does not describe them.

## Window Fundamentals

The AWT defines windows according to a class hierarchy that adds functionality and specificity with each level. Arguably the two most important window-related classes are **Frame** and **Panel**. **Frame** encapsulates a top-level window and it is typically used to create what would be thought of as a standard application window. **Panel** provides a container to which other components can be added. **Panel** is also a superclass for **Applet** (deprecated as of JDK 9). Much of the functionality of **Frame** and **Panel** is derived from their parent classes. Thus, a description of the class hierarchies relating to these two classes is fundamental to their understanding. Figure 25-1 shows the class hierarchy for **Panel** and **Frame**. Let’s look at each of these classes now.

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SystemColor</td>
<td>Contains the colors of GUI widgets such as windows, scroll bars, text, and others.</td>
</tr>
<tr>
<td>TextArea</td>
<td>Creates a multiline edit control.</td>
</tr>
<tr>
<td>TextComponent</td>
<td>A superclass for <strong>TextArea</strong> and <strong>TextField</strong>.</td>
</tr>
<tr>
<td>TextField</td>
<td>Creates a single-line edit control.</td>
</tr>
<tr>
<td>Toolkit</td>
<td>Abstract class implemented by the AWT.</td>
</tr>
<tr>
<td>Window</td>
<td>Creates a window with no frame, no menu bar, and no title.</td>
</tr>
</tbody>
</table>

Table 25-1  A Sampling of AWT Classes
Component

At the top of the AWT hierarchy is the Component class. Component is an abstract class that encapsulates all of the attributes of a visual component. Except for menus, all user interface elements that are displayed on the screen and that interact with the user are subclasses of Component. It defines over a hundred public methods that are responsible for managing events, such as mouse and keyboard input, positioning and sizing the window, and repainting. A Component object is responsible for remembering the current foreground and background colors and the currently selected text font.

Container

The Container class is a subclass of Component. It has additional methods that allow other Component objects to be nested within it. Other Container objects can be stored inside of a Container (since they are themselves instances of Component). This makes for a multileveled containment system. A container is responsible for laying out (that is, positioning) any components that it contains. It does this through the use of various layout managers, which you will learn about in Chapter 26.

Panel

The Panel class is a concrete subclass of Container. A Panel may be thought of as a recursively nestable, concrete screen component. Other components can be added to a Panel object by its add() method (inherited from Container). Once these
components have been added, you can position and resize them manually using the 
setLocation( ), setSize( ), setPreferredSize( ), or setBounds( ) methods defined by 
Component.

Window

The Window class creates a top-level window. A top-level window is not contained 
within any other object; it sits directly on the desktop. Generally, you won’t create 
Window objects directly. Instead, you will use a subclass of Window called Frame, 
described next.

Frame

Frame encapsulates what is commonly thought of as a “window.” It is a subclass of 
Window and has a title bar, menu bar, borders, and resizing corners. The precise 
look of a Frame will differ among environments.

Canvas

Although it is not part of the hierarchy for Panel or Frame, there is one other class 
that you will find valuable: Canvas. Derived from Component, Canvas 
encapsulates a blank window upon which you can draw. You will see an example of 
Canvas later in this book.

Working with Frame Windows

Typically, the type of AWT-based application window you will most often create is 
derived from Frame. As mentioned, it creates a standard-style, top-level window 
that has all of the features normally associated with an application window, such as a 
close box and title.

Here are two of Frame’s constructors:

Frame( ) throws HeadlessException
Frame(String title) throws HeadlessException

The first form creates a standard window that does not contain a title. The second 
form creates a window with the title specified by title. Notice that you cannot specify 
the dimensions of the window. Instead, you must set the size of the window after it 
has been created. A HeadlessException is thrown if an attempt is made to create a 
Frame instance in an environment that does not support user interaction.
There are several key methods you will use when working with Frame windows. They are examined here.

### Setting the Window’s Dimensions
The `setSize()` method is used to set the dimensions of the window. It is shown here:

```java
void setSize(int newWidth, int newHeight)
void setSize(Dimension newSize)
```

The new size of the window is specified by `newWidth` and `newHeight`, or by the `width` and `height` fields of the `Dimension` object passed in `newSize`. The dimensions are specified in terms of pixels.

The `getSize()` method is used to obtain the current size of a window. One of its forms is shown here:

```java
Dimension getSize()
```

This method returns the current size of the window contained within the `width` and `height` fields of a `Dimension` object.

### Hiding and Showing a Window
After a frame window has been created, it will not be visible until you call `setVisible()`. Its signature is shown here:

```java
void setVisible(boolean visibleFlag)
```

The component is visible if the argument to this method is `true`. Otherwise, it is hidden.

### Setting a Window’s Title
You can change the title in a frame window using `setTitle()`, which has this general form:

```java
void setTitle(String newTitle)
```

Here, `newTitle` is the new title for the window.

### Closing a Frame Window
When using a frame window, your program must remove that window from the screen when it is closed. If it is not the top-level window of your application, this is done by calling `setVisible(false)`. For the main application window, you can simply terminate the program by calling `System.exit()` as the examples in Chapter 24 did. To intercept a window-close event, you must implement the `windowClosing()` method of the `WindowListener` interface. (See Chapter 24 for details on the `WindowListener` interface.)

**The paint( ) Method**

As you saw in Chapter 24, output to a window typically occurs when the `paint( )` method is called by the run-time system. This method is defined by `Component` and overridden by `Container` and `Window`. Thus, it is available to instances of `Frame`.

The `paint( )` method is called each time an AWT-based application’s output must be redrawn. This situation can occur for several reasons. For example, the program’s window may be overwritten by another window and then uncovered. Or the window may be minimized and then restored. `paint( )` is also called when the window is first displayed. Whatever the cause, whenever the window must redraw its output, `paint( )` is called. This implies that your program must have some way to retain its output so that it can be redisplayed each time `paint( )` executes.

The `paint( )` method is shown here:

```java
void paint(Graphics context)
```

The `paint( )` method has one parameter of type `Graphics`. This parameter will contain the graphics context, which describes the graphics environment in which the program is running. This context is used whenever output to the window is required.

**Displaying a String**

To output a string to a `Frame`, use `drawString( )`, which is a member of the `Graphics` class. It was introduced in Chapter 24, and we will be making extensive use of it here and in the next chapter. This is the form we will use:

```java
void drawString(String message, int x, int y)
```

Here, `message` is the string to be output beginning at `x,y`. In a Java window, the upper-left corner is location 0,0. The `drawString( )` method will not recognize newline characters. If you want to start a line of text on another line, you must do so manually, specifying the precise X,Y location where you want the line to begin. (As you will see in the next chapter, there are techniques that make this process easy.)
Setting the Foreground and Background Colors

You can set both the foreground and background colors used by a Frame. To set the background color, use `setBackground()`. To set the foreground color (the color in which text is shown, for example), use `setForeground()`. These methods are defined by `Component`, and they have the following general forms:

```java
void setBackground(Color newColor)
void setForeground(Color newColor)
```

Here, `newColor` specifies the new color. The class `Color` defines the constants shown here that can be used to specify colors. (Uppercase versions of these constants are also provided.)

<table>
<thead>
<tr>
<th>Color.black</th>
<th>Color.magenta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color.blue</td>
<td>Color.orange</td>
</tr>
<tr>
<td>Color.cyan</td>
<td>Color.pink</td>
</tr>
<tr>
<td>Color.darkGray</td>
<td>Color.red</td>
</tr>
<tr>
<td>Color.gray</td>
<td>Color.white</td>
</tr>
<tr>
<td>Color.green</td>
<td>Color.yellow</td>
</tr>
<tr>
<td>Color.lightGray</td>
<td></td>
</tr>
</tbody>
</table>

For example, the following sets the background color to green and the foreground color to red:

```java
setBackground(Color.green);
setForeground(Color.red);
```

You can also create custom colors. A good place to initially set the foreground and background colors is in the constructor for the frame. Of course, you can change these colors as often as necessary during the execution of your program.

You can obtain the current settings for the background and foreground colors by calling `getBackground()` and `getForeground()`, respectively. They are also defined by `Component` and are shown here:

```java
Color getBackground() 
Color getForeground()
```
Requesting Repainting

As a general rule, an application writes to its window only when its `paint()` method is called by the AWT. This raises an interesting question: How can the program itself cause its window to be updated to display new output? For example, if a program displays a moving banner, what mechanism does it use to update the window each time the banner scrolls? Remember, one of the fundamental architectural constraints imposed on a GUI program is that it must quickly return control to the run-time system. It cannot create a loop inside `paint()` that repeatedly scrolls the banner, for example. This would prevent control from passing back to the AWT. Given this constraint, it may seem that output to your window will be difficult at best. Fortunately, this is not the case. Whenever your program needs to update the information displayed in its window, it simply calls `repaint()`.

The `repaint()` method is defined by `Component`. As it relates to `Frame`, this method causes the AWT run-time system to execute a call to the `update()` method (also defined by `Component`). However, the default implementation of `update()` calls `paint()`. Thus, to output to a window, simply store the output and then call `repaint()`. The AWT will then execute a call to `paint()`, which can display the stored information. For example, if part of your program needs to output a string, it can store this string in a `String` variable and then call `repaint()`. Inside `paint()`, you will output the string using `drawString()`.

The `repaint()` method has four forms. Let’s look at each one in turn. The simplest version of `repaint()` is shown here:

```java
void repaint()
```

This version causes the entire window to be repainted. The following version specifies a region that will be repainted:

```java
void repaint(int left, int top, int width, int height)
```

Here, the coordinates of the upper-left corner of the region are specified by `left` and `top`, and the width and height of the region are passed in `width` and `height`. These dimensions are specified in pixels. You save time by specifying a region to repaint. Window updates are costly in terms of time. If you need to update only a small portion of the window, it is more efficient to repaint only that region.

Calling `repaint()` is essentially a request that a window be repainted sometime soon. However, if your system is slow or busy, `update()` might not be called immediately. Multiple requests for repainting that occur within a short time can be collapsed by the AWT in a manner such that `update()` is only called sporadically.
This can be a problem in many situations, including animation, in which a consistent update time is necessary. One solution to this problem is to use the following forms of \texttt{repaint( )}:

\begin{verbatim}
    void repaint(long maxDelay)
    void repaint(long maxDelay, int x, int y, int width, int height)
\end{verbatim}

Here, \textit{maxDelay} specifies the maximum number of milliseconds that can elapse before \texttt{update( )} is called.

\textbf{NOTE} It is possible for a method other than \texttt{paint( )} or \texttt{update( )} to output to a window. To do so, it must obtain a graphics context by calling \texttt{getGraphics( )} (defined by \texttt{Component}) and then use this context to output to the window. However, for most applications, it is better and easier to route window output through \texttt{paint( )} and to call \texttt{repaint( )} when the contents of the window change.

\section*{Creating a Frame-Based Application}

While it is possible to simply create a window by creating an instance of \texttt{Frame}, you will seldom do so, because you would not be able to do much with it. For example, you would not be able to receive or process events that occur within it or easily output information to it. Therefore, to create a \texttt{Frame}-based application, you will normally create a subclass of \texttt{Frame}. Among other reasons, doing so lets you override \texttt{paint( )} and provide event handling.

As the event handling examples in Chapter 24 illustrated, creating a new \texttt{Frame}-based application is actually quite easy. In general, you create a subclass of \texttt{Frame}, override \texttt{paint( )} to supply your output to the window, and implement the necessary event listeners. In all cases, you will need to implement the \texttt{windowClosing( )} method of the \texttt{WindowListener} interface. In a top-level frame, you will typically call \texttt{System.exit( )} to terminate the program. To simply remove a secondary frame from the screen, you can call \texttt{setVisible(false)} when the window is closed.

Once you have defined a \texttt{Frame} subclass, you can create an instance of that class. This causes a frame window to come into existence, but it will not be initially visible. You make it visible by calling \texttt{setVisible(true)}. When created, the window is given a default height and width. You can set the size of the window explicitly by calling the \texttt{setSize( )} method. For a top-level frame, you will want to define its title.

\section*{Introducing Graphics}

The AWT includes several methods that support graphics. All graphics are drawn
relative to a window. This can be the main window of an application or a child window. (These methods are also supported by Swing-based windows.) The origin of each window is at the top-left corner and is 0,0. Coordinates are specified in pixels. All output to a window takes place through a graphics context.

A graphics context is encapsulated by the Graphics class. Here are two ways in which a graphics context can be obtained:

- It is passed to a method, such as paint() or update(), as an argument.
- It is returned by the getGraphics() method of Component.

Among other things, the Graphics class defines a number of methods that draw various types of objects, such as lines, rectangles, and arcs. In several cases, objects can be drawn edge-only or filled. Objects are drawn and filled in the currently selected color, which is black by default. When a graphics object is drawn that exceeds the dimensions of the window, output is automatically clipped. A sampling of the drawing methods supported by Graphics is presented here.

NOTE With the release of version 1.2, the graphics capabilities of Java were expanded by the inclusion of several new classes. One of these is Graphics2D, which extends Graphics. Graphics2D supports several enhancements to the basic capabilities provided by Graphics. To gain access to this extended functionality, you must cast the graphics context obtained from a method such as paint(), to Graphics2D. Although the basic graphics functions supported by Graphics are adequate for the purposes of this book, Graphics2D is a class that you may want to explore fully on your own.

### Drawing Lines

Lines are drawn by means of the drawLine() method, shown here:

```java
void drawLine(int startX, int startY, int endX, int endY)
```

drawLine() displays a line in the current drawing color that begins at startX, startY and ends at endX, endY.

### Drawing Rectangles

The drawRect() and fillRect() methods display an outlined and filled rectangle, respectively. They are shown here:

```java
void drawRect(int left, int top, int width, int height)
```
void fillRect(int left, int top, int width, int height)

The upper-left corner of the rectangle is at left, top. The dimensions of the rectangle are specified by width and height.

To draw a rounded rectangle, use `drawRoundRect()` or `fillRoundRect()`, both shown here:

```c
void drawRoundRect(int left, int top, int width, int height,
                   int xDiam, int yDiam)
void fillRoundRect(int left, int top, int width, int height,
                   int xDiam, int yDiam)
```

A rounded rectangle has rounded corners. The upper-left corner of the rectangle is at left, top. The dimensions of the rectangle are specified by width and height. The diameter of the rounding arc along the X axis is specified by xDiam. The diameter of the rounding arc along the Y axis is specified by yDiam.

**Drawing Ellipses and Circles**

To draw an ellipse, use `drawOval()`. To fill an ellipse, use `fillOval()`. These methods are shown here:

```c
void drawOval(int left, int top, int width, int height)
void fillOval(int left, int top, int width, int height)
```

The ellipse is drawn within a bounding rectangle whose upper-left corner is specified by left, top and whose width and height are specified by width and height. To draw a circle, specify a square as the bounding rectangle.

**Drawing Arcs**

Arcs can be drawn with `drawArc()` and `fillArc()`, shown here:

```c
void drawArc(int left, int top, int width, int height, int startAngle, int sweepAngle)
void fillArc(int left, int top, int width, int height, int startAngle, int sweepAngle)
```

The arc is bounded by the rectangle whose upper-left corner is specified by left, top and whose width and height are specified by width and height. The arc is drawn from startAngle through the angular distance specified by sweepAngle. Angles are specified in degrees. Zero degrees is on the horizontal, at the three o’clock position. The arc is drawn counterclockwise if sweepAngle is positive, and clockwise if sweepAngle is negative. Therefore, to draw an arc from twelve o’clock to six
o’clock, the start angle would be 90 and the sweep angle 180.

**Drawing Polygons**

It is possible to draw arbitrarily shaped figures using `drawPolygon()` and `fillPolygon()`, shown here:

```c
void drawPolygon(int x[], int y[], int numPoints)
void fillPolygon(int x[], int y[], int numPoints)
```

The polygon’s endpoints are specified by the coordinate pairs contained within the `x` and `y` arrays. The number of points defined by these arrays is specified by `numPoints`. There are alternative forms of these methods in which the polygon is specified by a `Polygon` object.

**Demonstrating the Drawing Methods**

The following program demonstrates the drawing methods just described.
// Draw graphics elements.
import java.awt.event.*;
import java.awt.*;

public class GraphicsDemo extends Frame {

    public GraphicsDemo() {
        // Anonymous inner class to handle window close events.
        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }

    public void paint(Graphics g) {

        // Draw lines.
        g.drawLine(20, 40, 100, 90);
        g.drawLine(20, 90, 100, 40);
        g.drawLine(40, 45, 250, 80);

        // Draw rectangles.
        g.drawRect(20, 150, 60, 50);
        g.fillRect(110, 150, 60, 50);
        g.drawRect(200, 150, 60, 50, 15, 15);
        g.fillRect(290, 150, 60, 50, 30, 40);

        // Draw elipses and circles.
        g.drawOval(20, 250, 50, 50);
        g.fillOval(100, 250, 75, 50);
        g.drawOval(200, 260, 100, 40);

        // Draw arcs.
        g.drawArc(20, 350, 70, 70, 0, 180);
        g.fillArc(70, 350, 70, 70, 0, 75);

        // Draw a polygon.
        int xpoints[] = {20, 200, 20, 200, 20};
        int ypoints[] = {450, 450, 650, 650, 450};
        int num = 5;

        g.drawPolygon(xpoints, ypoints, num);
    }

    public static void main(String[] args) {
        GraphicsDemo appwin = new GraphicsDemo();
    }
}
Sample output is shown in Figure 25-1.

Figure 25-1  Sample output from the GraphicsDemo program
Sizing Graphics

Often, you will want to size a graphics object to fit the current size of the frame in which it is drawn. To do so, first obtain the current dimensions of the frame by calling `getSize()`. It returns the dimensions as integer values stored in the `width` and `height` fields of a `Dimension` instance. However, the dimensions returned by `getSize()` reflect the overall size of the frame, including border and title bar. To obtain the dimensions of the paintable area, you will need to reduce the size obtained from `getSize()` by the dimensions of the border/title bar. The values that describe the size of the border/title region are called *insets*. The inset values are obtained by calling `getInsets()`, shown here:

```
Insets getInsets()
```

It returns an `Insets` object that encapsulates the insets dimensions as four `int` values called `left`, `right`, `top`, and `bottom`. Therefore, the coordinate of the top-left corner of the paintable area is `left, top`. The coordinate of the bottom-right corner is `width−right, height−bottom`. Once you have both the size and insets, you can scale your graphical output accordingly.

To demonstrate this technique, here is a program whose frame starts with dimensions 200Í200 pixels. It grows by 25 in both width and height each time the mouse is clicked until the size is larger than 500Í500. At that point, the next click will return it to 200Í200, and the process starts over. Within the paintable area, an X is drawn so that it fills the region.
public class ResizeMe extends Frame {
    final int inc = 25;
    int max = 500;
    int min = 200;
    Dimension d;

    public ResizeMe() {
        // Anonymous inner class to handle mouse release events.
        addMouseListener(new MouseAdapter() {
            public void mouseReleased(MouseEvent me) {
                int w = (d.width + inc) > max?min:(d.width + inc);
                int h = (d.height + inc) > max?min:(d.height + inc);
                setSize(new Dimension(w, h));
            }
        });

        // Anonymous inner class to handle window close events.
        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }

    public void paint(Graphics g) {
        Insets i = getInsets();
        d = getSize();

        g.drawLine(i.left, i.top, d.width-i.right, d.height-i.bottom);
        g.drawLine(i.left, d.height-i.bottom, d.width-i.right, i.top);
    }

    public static void main(String[] args) {
        ResizeMe appwin = new ResizeMe();

        appwin.setSize(new Dimension(200, 200));
        appwin.setTitle("ResizeMe");
        appwin.setVisible(true);
    }
}
Working with Color

Java supports color in a portable, device-independent fashion. The AWT color system allows you to specify any color you want. It then finds the best match for that color, given the limits of the display hardware currently executing your program. Thus, your code does not need to be concerned with the differences in the way color is supported by various hardware devices. Color is encapsulated by the `Color` class.

As you saw earlier, `Color` defines several constants (for example, `Color.black`) to specify a number of common colors. You can also create your own colors, using one of the `Color` constructors. Three commonly used forms are shown here:

```
Color(int red, int green, int blue)
Color(int rgbValue)
Color(float red, float green, float blue)
```

The first constructor takes three integers that specify the color as a mix of red, green, and blue. These values must be between 0 and 255, as in this example:

```
new Color(255, 100, 100); // light red
```

The second color constructor takes a single integer that contains the mix of red, green, and blue packed into an integer. The integer is organized with red in bits 16 to 23, green in bits 8 to 15, and blue in bits 0 to 7. Here is an example of this constructor:

```
int newRed = (0xff000000 | (0xc0 << 16) | (0x00 << 8) | 0x00);
Color darkRed = new Color(newRed);
```

The third constructor, `Color(float, float, float)`, takes three `float` values (between 0.0 and 1.0) that specify the relative mix of red, green, and blue.

Once you have created a color, you can use it to set the foreground and/or background color by using the `setForeground()` and `setBackground()` methods as mentioned earlier. You can also select it as the current drawing color.

**Color Methods**

The `Color` class defines several methods that help manipulate colors. Several are examined here.

**Using Hue, Saturation, and Brightness**
The hue-saturation-brightness (HSB) color model is an alternative to red-green-blue (RGB) for specifying particular colors. Figuratively, hue is a wheel of color. The hue can be specified with a number between 0.0 and 1.0, which is used to obtain an angle into the color wheel. (The principal colors are approximately red, orange, yellow, green, blue, indigo, and violet.) Saturation is another scale ranging from 0.0 to 1.0, representing light pastels to intense hues. Brightness values also range from 0.0 to 1.0, where 1 is bright white and 0 is black. Color supplies two methods that let you convert between RGB and HSB. They are shown here:

```java
static int HSBtoRGB(float hue, float saturation, float brightness)
static float[ ] RGBtoHSB(int red, int green, int blue, float values[ ])
```

HSBtoRGB( ) returns a packed RGB value compatible with the Color(int) constructor. RGBtoHSB( ) returns a float array of HSB values corresponding to RGB integers. If values is not null, then this array is given the HSB values and returned. Otherwise, a new array is created and the HSB values are returned in it. In either case, the array contains the hue at index 0, saturation at index 1, and brightness at index 2.

**getRed( ), getGreen( ), getBlue( )**

You can obtain the red, green, and blue components of a color independently using getRed( ), getGreen( ), and getBlue( ), shown here:

```java
int getRed( )
int getGreen( )
int getBlue( )
```

Each of these methods returns the RGB color component found in the invoking Color object in the lower 8 bits of an integer.

**getRGB( )**

To obtain a packed, RGB representation of a color, use getRGB( ), shown here:

```java
int getRGB( )
```

The return value is organized as described earlier.

**Setting the Current Graphics Color**

By default, graphics objects are drawn in the current foreground color. You can change this color by calling the Graphics method setColor( ):

```java
void setColor(Color newColor)
```
Here, newColor specifies the new drawing color.

You can obtain the current color by calling getColor(), shown here:

```java
Color getColor()
```

### A Color Demonstration Program

The following program constructs several colors and draws various objects using these colors:

```java
// Demonstrate color.
import java.awt.*;
import java.awt.event.*;

public class ColorDemo extends Frame {
  public ColorDemo() {
    addWindowListener(new WindowAdapter() {
      public void windowClosing(WindowEvent we) {
        System.exit(0);
      }
    });
  }

  // Draw in different colors.
  public void paint(Graphics g) {
    Color c1 = new Color(255, 100, 100);
    Color c2 = new Color(100, 255, 100);
    Color c3 = new Color(100, 100, 255);

    g.setColor(c1);
    g.drawLine(20, 40, 100, 100);
    g.drawLine(20, 100, 100, 20);

    g.setColor(c2);
    g.drawLine(40, 45, 250, 180);
    g.drawLine(75, 90, 400, 400);

    g.setColor(c3);
    g.drawLine(20, 150, 400, 40);
    g.drawLine(25, 290, 80, 19);
  }
}
```
Setting the Paint Mode

The paint mode determines how objects are drawn in a window. By default, new output to a window overwrites any preexisting contents. However, it is possible to have new objects XORed onto the window by using setXORMode(), as follows:

```java
void setXORMode(Color xorColor)
```

Here, xorColor specifies the color that will be XORed to the window when an object is drawn. The advantage of XOR mode is that the new object is always guaranteed to be visible no matter what color the object is drawn over.

To return to overwrite mode, call setPaintMode(), shown here:

```java
void setPaintMode()
```

In general, you will want to use overwrite mode for normal output, and XOR mode for special purposes. For example, the following program displays cross hairs that track the mouse pointer. The cross hairs are XORed onto the window and are always visible, no matter what the underlying color is.
// Demonstrate XOR mode.
import java.awt.*;
import java.awt.event.*;

public class XOR extends Frame {
    int chsX=100, chsY=100;

    public XOR() {
        addMouseMotionListener(new MouseMotionAdapter() {
            public void mouseMoved(MouseEvent me) {
                int x = me.getX();
                int y = me.getY();
                chsX = x-10;
                chsY = y-10;
                repaint();
            }
        });

        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }

    // Demonstrate XOR mode.
    public void paint(Graphics g) {
        g.setColor(Color.green);
        g.fillRect(20, 40, 60, 70);

        g.setColor(Color.blue);
        g.fillRect(110, 40, 60, 70);
    }
}
Working with Fonts

The AWT supports multiple type fonts. Years ago, fonts emerged from the domain of traditional typesetting to become an important part of computer-generated
documents and displays. The AWT provides flexibility by abstracting font-manipulation operations and allowing for dynamic selection of fonts.

Fonts have a family name, a logical font name, and a face name. The family name is the general name of the font, such as Courier. The logical name specifies a name, such as Monospaced, that is linked to an actual font at runtime. The face name specifies a specific font, such as Courier Italic.

Fonts are encapsulated by the Font class. Several of the methods defined by Font are listed in Table 25-2.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static Font decode(String str)</td>
<td>Returns a font given its name.</td>
</tr>
<tr>
<td>boolean equals(Object FontObj)</td>
<td>Returns true if the invoking object contains the same font as that specified by FontObj. Otherwise, it returns false.</td>
</tr>
<tr>
<td>String getFamily( )</td>
<td>Returns the name of the font family to which the invoking font belongs.</td>
</tr>
<tr>
<td>static Font getFont(String property)</td>
<td>Returns the font associated with the system property specified by property. null is returned if property does not exist.</td>
</tr>
<tr>
<td>static Font getFont(String property, Font defaultFont)</td>
<td>Returns the font associated with the system property specified by property. The font specified by defaultFont is returned if property does not exist.</td>
</tr>
<tr>
<td>String getFontName()</td>
<td>Returns the face name of the invoking font.</td>
</tr>
<tr>
<td>String getName( )</td>
<td>Returns the logical name of the invoking font.</td>
</tr>
<tr>
<td>int getSize( )</td>
<td>Returns the size, in points, of the invoking font.</td>
</tr>
<tr>
<td>int getStyle( )</td>
<td>Returns the style values of the invoking font.</td>
</tr>
<tr>
<td>int hashCode( )</td>
<td>Returns the hash code associated with the invoking object.</td>
</tr>
<tr>
<td>boolean isBold( )</td>
<td>Returns true if the font includes the BOLD style value. Otherwise, false is returned.</td>
</tr>
<tr>
<td>boolean isItalic( )</td>
<td>Returns true if the font includes the ITALIC style value. Otherwise, false is returned.</td>
</tr>
<tr>
<td>boolean isPlain( )</td>
<td>Returns true if the font includes the PLAIN style value. Otherwise, false is returned.</td>
</tr>
<tr>
<td>String toString( )</td>
<td>Returns the string equivalent of the invoking font.</td>
</tr>
</tbody>
</table>
Table 25-2 A Sampling of Methods Defined by Font

The Font class defines these protected variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>String name</td>
<td>Name of the font</td>
</tr>
<tr>
<td>float pointSize</td>
<td>Size of the font in points</td>
</tr>
<tr>
<td>int size</td>
<td>Size of the font in points</td>
</tr>
<tr>
<td>int style</td>
<td>Font style</td>
</tr>
</tbody>
</table>

Several static fields are also defined.

Determining the Available Fonts

When working with fonts, often you need to know which fonts are available on your machine. To obtain this information, you can use the `getAvailableFontFamilyNames()` method defined by the GraphicsEnvironment class. It is shown here:

```java
String[ ] getAvailableFontFamilyNames( )
```

This method returns an array of strings that contains the names of the available font families.

In addition, the `getAllFonts()` method is defined by the GraphicsEnvironment class. It is shown here:

```java
Font[ ] getAllFonts( )
```

This method returns an array of Font objects for all of the available fonts.

Since these methods are members of GraphicsEnvironment, you need a GraphicsEnvironment reference to call them. You can obtain this reference by using the `getLocalGraphicsEnvironment()` static method, which is defined by GraphicsEnvironment. It is shown here:

```java
static GraphicsEnvironment getLocalGraphicsEnvironment( )
```

Here is a program that shows how to obtain the names of the available font families:
import java.awt.event.*;
import java.awt.*;

public class ShowFonts extends Frame {
    String msg = "First five fonts: ";
    GraphicsEnvironment ge;

    public ShowFonts() {
        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }

    // Get the graphics environment.
    ge = GraphicsEnvironment.getLocalGraphicsEnvironment();

    // Obtain a list of the fonts.
    String[] fontList = ge.getAvailableFontFamilyNames();

    // Create a string of the first 5 fonts.
    for(int i=0; (i < 5) && (i < fontList.length); i++)
        msg += fontList[i] + " ";

    // Display the fonts.
    public void paint(Graphics g) {
        g.drawString(msg, 10, 60);
    }

    public static void main(String[] args) {
        ShowFonts appwin = new ShowFonts();

        appwin.setSize(new Dimension(500, 100));
        appwin.setTitle("ShowFonts");
        appwin.setVisible(true);
    }
}

Sample output from this program is shown next. However, when you run this
program, you may see a different set of fonts than the one shown in this illustration.
Creating and Selecting a Font

To create a new font, construct a Font object that describes that font. One Font constructor has this general form:

```java
Font(String fontName, int fontStyle, int pointSize)
```

Here, `fontName` specifies the name of the desired font. The name can be specified using either the family or face name. All Java environments will support the following fonts: Dialog, DialogInput, SansSerif, Serif, and Monospaced. Dialog is the font used by your system’s dialog boxes. Dialog is also the default if you don’t explicitly set a font. You can also use any other fonts supported by your particular environment, but be careful—these other fonts may not be universally available.

The style of the font is specified by `fontStyle`. It may consist of one or more of these three constants: Font.PLAIN, Font.BOLD, and Font.ITALIC. To combine styles, OR them together. For example, Font.BOLD | Font.ITALIC specifies a bold, italics style.

The size, in points, of the font is specified by `pointSize`.

To use a font that you have created, you must select it using `setFont()`, which is defined by Component. It has this general form:

```java
void setFont(Font fontObj)
```

Here, `fontObj` is the object that contains the desired font.

The following program outputs a sample of each standard font. Each time you click the mouse within its window, a new font is selected and its name is displayed.

```java
// Display fonts.
import java.awt.*;
import java.awt.event.*;

class SampleFonts extends Frame {
  int next = 0;
  Font f;
  String msg;
```
public SampleFonts() {
    f = new Font("Dialog", Font.PLAIN, 12);
    msg = "Dialog";
   setFont(f);

    addMouseListener(new MyMouseAdapter(this));

    addWindowListener(new WindowAdapter() {
        public void windowClosing(WindowEvent we) {
            System.exit(0);
        }
    });

}  

public void paint(Graphics g) {
    g.drawString(msg, 10, 60);
}  

public static void main(String[] args) {
    SampleFonts appwin = new SampleFonts();

    appwin.setSize(new Dimension(200, 100));
    appwin.setTitle("SampleFonts");
    appwin.setVisible(true);
}
class MyMouseAdapter extends MouseAdapter {
    SampleFonts sampleFonts;

    public MyMouseAdapter(SampleFonts sampleFonts) {
        this.sampleFonts = sampleFonts;
    }

    public void mousePressed(MouseEvent me) {
        // Switch fonts with each mouse click.
        sampleFonts.next++;;

        switch(sampleFonts.next) {
            case 0:
                sampleFonts.f = new Font("Dialog", Font.PLAIN, 12);
                sampleFonts.msg = "Dialog";
                break;
            case 1:
                sampleFonts.f = new Font("DialogInput", Font.PLAIN, 12);
                sampleFonts.msg = "DialogInput";
                break;
            case 2:
                sampleFonts.f = new Font("SansSerif", Font.PLAIN, 12);
                sampleFonts.msg = "SansSerif";
                break;
            case 3:
                sampleFonts.f = new Font("Serif", Font.PLAIN, 12);
                sampleFonts.msg = "Serif";
                break;
            case 4:
                sampleFonts.f = new Font("Monospaced", Font.PLAIN, 12);
                sampleFonts.msg = "Monospaced";
                break;
        }

        if(sampleFonts.next == 4) sampleFonts.next = -1;
        sampleFonts.setFont(sampleFonts.f);
        sampleFonts.repaint();
    }
}

Sample output from this program is shown here:
Obtaining Font Information

Suppose you want to obtain information about the currently selected font. To do this, you must first get the current font by calling `setFont()`. This method is defined by the `Graphics` class, as shown here:

```java
Font getFont()
```

Once you have obtained the currently selected font, you can retrieve information about it using various methods defined by `Font`. For example, this program displays the name, family, size, and style of the currently selected font:

```java
// Display font info.
import java.awt.event.*;
import java.awt.*;

public class FontInfo extends Frame {

    public FontInfo() {
        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }

    public void paint(Graphics g) {
        Font f = g.getFont();
        String fontName = f.getName();
        String fontFamily = f.getFamily();
        int fontSize = f.getSize();
        int fontStyle = f.getStyle();
    }
}
```
As just explained, Java supports a number of fonts. For most fonts, characters are not all the same dimension—most fonts are proportional. Also, the height of each character, the length of descenders (the hanging parts of letters, such as y), and the amount of space between horizontal lines vary from font to font. Further, the point size of a font can be changed. That these (and other) attributes are variable would not be of too much consequence except that Java demands that you, the programmer, manually manage virtually all text output.

Given that the size of each font may differ and that fonts may be changed while your program is executing, there must be some way to determine the dimensions and various other attributes of the currently selected font. For example, to write one line of text after another implies that you have some way of knowing how tall the font is and how many pixels are needed between lines. To fill this need, the AWT includes the FontMetrics class, which encapsulates various information about a font. Let’s begin by defining the common terminology used when describing fonts:
As you know, we have used the `drawString()` method in many of the previous examples. It paints a string in the current font and color, beginning at a specified location. However, this location is at the left edge of the baseline of the characters, not at the upper-left corner as is usual with other drawing methods. It is a common error to draw a string at the same coordinate that you would draw a box. For example, if you were to draw a rectangle at the top, left location, you would see a full rectangle. If you were to draw the string “Typesetting” at this location, you would only see the tails (or descenders) of the y, p, and g. As you will see, by using font metrics, you can determine the proper placement of each string that you display.

**FontMetrics** defines several methods that help you manage text output. A number of commonly used ones are listed in Table 25-3. These methods help you properly display text in a window.

<table>
<thead>
<tr>
<th>Height</th>
<th>The top-to-bottom size of a line of text</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>The line that the bottoms of characters are aligned to (not counting descent)</td>
</tr>
<tr>
<td>Ascent</td>
<td>The distance from the baseline to the top of a character</td>
</tr>
<tr>
<td>Descent</td>
<td>The distance from the baseline to the bottom of a character</td>
</tr>
<tr>
<td>Leading</td>
<td>The distance between the bottom of one line of text and the top of the next</td>
</tr>
</tbody>
</table>
Perhaps the most common use of FontMetrics is to determine the spacing between lines of text. The second most common use is to determine the length of a string that is being displayed. Here, you will see how to accomplish these tasks.

In general, to display multiple lines of text, your program must manually keep track of the current output position. Each time a newline is desired, the Y coordinate must be advanced to the beginning of the next line. Each time a string is displayed, the X coordinate must be set to the point at which the string ends. This allows the next string to be written so that it begins at the end of the preceding one.

To determine the spacing between lines, you can use the value returned by `getLeading()` . To determine the total height of the font, add the value returned by `getAscent()` to the value returned by `getDescent()` . You can then use these values to position each line of text you output. However, in many cases, you will not need to
use these individual values. Often, all that you will need to know is the total height of a line, which is the sum of the leading space and the font’s ascent and descent values. The easiest way to obtain this value is to call `getHeight()`. In many cases, you can simply increment the Y coordinate by this value each time you want to advance to the next line when outputting text.

To start output at the end of previous output on the same line, you must know the length, in pixels, of each string that you display. To obtain this value, call `stringWidth()`. You can use this value to advance the X coordinate each time you display a line.

The following program shows how to output multiple lines of text in a window. It also displays multiple sentences on the same line. Notice the variables `curX` and `curY`. They keep track of the current text output position.
/ Demonstrate multiline output.
import java.awt.event.*;
import java.awt.*;

public class MultiLine extends Frame {
    int curX=20, curY=40; // current position

    public MultiLine() {
        Font f = new Font("SansSerif", Font.PLAIN, 12);
       setFont(f);

        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }

    public void paint(Graphics g) {
        FontMetrics fm = g.getFontMetrics();

        nextLine("This is on line one.", g);
        nextLine("This is on line two.", g);
        sameLine(" This is on same line.", g);
        sameLine(" This, too.", g);
        nextLine("This is on line three.", g);

        curX = 20; curY = 40; // reset the coordinates for each repaint
    }

    // Advance to next line.
    void nextLine(String s, Graphics g) {
        FontMetrics fm = g.getFontMetrics();
    }
curY += fm getHeight(); // advance to next line
curX = 20;
g.drawString(s, curX, curY);
curX += fm.stringWidth(s); // advance to end of line

// Display on same line.
void sameLine(String s, Graphics g) {
    FontMetrics fm = g.getFontMetrics();

    g.drawString(s, curX, curY);
curX += fm.stringWidth(s); // advance to end of line
}

public static void main(String[] args) {
    MultiLine appwin = new MultiLine();

    appwin.setSize(new Dimension(300, 120));
    appwin.setTitle("MultiLine");
    appwin.setVisible(true);
}

Sample output from this program is shown here:
This chapter continues our overview of the Abstract Window Toolkit (AWT). It begins with a look at several of the AWT’s controls and layout managers. It then discusses menus and the menu bar. The chapter also includes a discussion of the dialog box.

Controls are components that allow a user to interact with your application in various ways—for example, a commonly used control is the push button. A layout manager automatically positions components within a container. Thus, the appearance of a window is determined by a combination of the controls that it contains and the layout manager used to position them.

In addition to the controls, a frame window can also include a standard-style menu bar. Each entry in a menu bar activates a drop-down menu of options from which the user can choose. This constitutes the main menu of an application. As a general rule, a menu bar is positioned at the top of a window. Although different in appearance, menu bars are handled in much the same way as are the other controls.

While it is possible to manually position components within a window, doing so is quite tedious. The layout manager automates this task. For the first part of this chapter, which introduces various controls, a simple layout manager will be used that displays components in a container using line-by-line, top-to-bottom organization. Once the controls have been covered, several other layout managers will be examined. There, you will see ways to better manage the positioning of controls.

Before continuing, it is important to emphasize that today you will seldom create GUIs based solely on the AWT because more powerful GUI frameworks (Swing and JavaFX) have been developed for Java. However, the material presented here remains important for the following reasons. First, much of the information and many of the techniques related to controls and event handling are generalizable to the other Java GUI frameworks. (As mentioned in the previous chapter, Swing is built upon the AWT.) Second, the layout managers described here are also used by Swing. Third, for some small applications, the AWT components might be the appropriate choice. Finally, you may encounter legacy code that uses the AWT. Therefore, a basic understanding of the AWT is important for all Java programmers.
AWT Control Fundamentals

The AWT supports the following types of controls:

- Labels
- Push buttons
- Check boxes
- Choice lists
- Lists
- Scroll bars
- Text Editing

All AWT controls are subclasses of Component. Although the set of controls provided by the AWT is not particularly rich, it is sufficient for simple applications, such as short utility programs intended for your own use. It is also quite useful for introducing the basic concepts and techniques related to handling events in controls. It is important to point out, however, that both Swing and JavaFX provide a substantially larger, more sophisticated set of controls, and that you will typically use one of those frameworks when creating commercial applications.

Adding and Removing Controls

To include a control in a window, you must add it to the window. To do this, you must first create an instance of the desired control and then add it to a window by calling add(), which is defined by Container. The add() method has several forms. The following form is the one that is used for the first part of this chapter:

Component add(Component compRef)

Here, compRef is a reference to an instance of the control that you want to add. A reference to the object is returned. Once a control has been added, it will automatically be visible whenever its parent window is displayed.

Sometimes you will want to remove a control from a window when the control is no longer needed. To do this, call remove( ). This method is also defined by Container. Here is one of its forms:

void remove( Component compRef )

Here, compRef is a reference to the control you want to remove. You can remove all controls by calling removeAll().
Responding to Controls
Except for labels, which are passive, all other controls generate events when they are accessed by the user. For example, when the user clicks on a push button, an event is sent that identifies the push button. In general, your program simply implements the appropriate interface and then registers an event listener for each control that you need to monitor. As explained in Chapter 24, once a listener has been installed, events are automatically sent to it. In the sections that follow, the appropriate interface for each control is specified.

The HeadlessException
Most of the AWT controls described in this chapter have constructors that can throw a HeadlessException when an attempt is made to instantiate a GUI component in a non-interactive environment (such as one in which no display, mouse, or keyboard is present). You can use this exception to write code that can adapt to non-interactive environments. (Of course, this is not always possible.) This exception is not handled by the programs in this chapter because an interactive environment is required to demonstrate the AWT controls.

Labels
The easiest control to use is a label. A label is an object of type Label, and it contains a string, which it displays. Labels are passive controls that do not support any interaction with the user. Label defines the following constructors:

- Label() throws HeadlessException
- Label(String str) throws HeadlessException
- Label(String str, int how) throws HeadlessException

The first version creates a blank label. The second version creates a label that contains the string specified by str. This string is left-justified. The third version creates a label that contains the string specified by str using the alignment specified by how. The value of how must be one of these three constants: Label.LEFT, Label.RIGHT, or Label.CENTER.

You can set or change the text in a label by using the setText( ) method. You can obtain the current label by calling getText( ). These methods are shown here:

void setText(String str)
String getText( )
For `setText()`, `str` specifies the new label. For `getText()`, the current label is returned.

You can set the alignment of the string within the label by calling `setAlignment()` . To obtain the current alignment, call `getAlignment()`. The methods are as follows:

```java
void setAlignment(int how)
int getAlignment()
```

Here, `how` must be one of the alignment constants shown earlier.

The following example creates three labels and adds them to a `Frame`.

```java
// Demonstrate Labels.
import java.awt.*;
import java.awt.event.*;

public class LabelDemo extends Frame {
    public LabelDemo() {
```
Here is sample output from the LabelDemo program.

Notice that the labels are organized in the window left-to-right. This is handled automatically by the FlowLayout layout manager, which is one of the layout managers provided by the AWT. Here it is used in its default configuration, which lays out components line-by-line, left-to-right, top-to-bottom, and centered. As you will see later in this chapter, it supports several options, but for now, its default behavior is sufficient. Notice that FlowLayout is selected as the layout manager by use of setDefaultCloseOperation(). This method sets the layout manager associated with the container, which in this case is the enclosing frame. Although FlowLayout is very
convenient and sufficient for our purposes at this time, it does not give you detailed control over the placement of components within a window. Later in this chapter, when the topic of layout managers is examined in detail, you will see how to gain more control over the organization of your windows.

Using Buttons

Perhaps the most widely used control is the push button. A *push button* is a component that contains a label and generates an event when it is pressed. Push buttons are objects of type **Button**. **Button** defines these two constructors:

```
Button( ) throws HeadlessException
Button(String str) throws HeadlessException
```

The first version creates an empty button. The second creates a button that contains `str` as a label.

After a button has been created, you can set its label by calling `setLabel( )`. You can retrieve its label by calling `getLabel( )`. These methods are as follows:

```
void setLabel(String str)
String getLabel( )
```

Here, `str` becomes the new label for the button.

Handling Buttons

Each time a button is pressed, an action event is generated. This is sent to any listeners that previously registered an interest in receiving action event notifications from that component. Each listener implements the **ActionListener** interface. That interface defines the `actionPerformed( )` method, which is called when an event occurs. An **ActionEvent** object is supplied as the argument to this method. It contains both a reference to the button that generated the event and a reference to the *action command string* associated with the button. By default, the action command string is the label of the button. Either the button reference or the action command string can be used to identify the button. (You will soon see examples of each approach.)

Here is an example that creates three buttons labeled "Yes", "No", and "Undecided". Each time one is pressed, a message is displayed that reports which button has been pressed. In this version, the action command of the button (which, by default, is its label) is used to determine which button has been pressed. The label
is obtained by calling the `getActionCommand()` method on the `ActionEvent` object passed to `actionPerformed()`.

```java
// Demonstrate Buttons.
import java.awt.*;
import java.awt.event.*;

public class ButtonDemo extends Frame implements ActionListener {
    String msg = "";
    Button yes, no, maybe;

    public ButtonDemo() {
        // Use a flow layout.
        setLayout(new FlowLayout());

        // Create some buttons.
        yes = new Button("Yes");
        no = new Button("No");
        maybe = new Button("Undecided");

        // Add them to the frame.
        add(yes);
        add(no);
        add(maybe);

        // Add action listeners for the buttons.
        yes.addActionListener(this);
        no.addActionListener(this);
        maybe.addActionListener(this);

        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }
}
```
// Handle button action events.
public void actionPerformed(ActionEvent ae) {
    String str = ae.getActionCommand();
    if(str.equals("Yes")) {
        msg = "You pressed Yes.";
    }
    else if(str.equals("No")) {
        msg = "You pressed No.";
    }
    else {
        msg = "You pressed Undecided.";
    }

    repaint();
}

public void paint(Graphics g) {
    g.drawString(msg, 20, 100);
}

public static void main(String[] args) {
    ButtonDemo appwin = new ButtonDemo();

    appwin.setSize(new Dimension(250, 150));
    appwin.setTitle("ButtonDemo");
    appwin.setVisible(true);
}

Sample output from the ButtonDemo program is shown in Figure 26-1.

![Figure 26-1](image)

As mentioned, in addition to comparing button action command strings, you can also determine which button has been pressed by comparing the object obtained from the `getSource()` method to the button objects that you added to the window. To do
this, you must keep a list of the objects when they are added. The following program shows this approach:

```java
// Recognize Button objects.
import java.awt.*;
import java.awt.event.*;

public class ButtonList extends Frame implements ActionListener {
    String msg = "";
    Button bList[] = new Button[3];

    public ButtonList() {

        // Use a flow layout.
        setLayout(new FlowLayout());

        // Create some buttons.
        Button yes = new Button("Yes");
        Button no = new Button("No");
        Button maybe = new Button("Undecided");

        // Store references to buttons as added.
        bList[0] = (Button) add(yes);
        bList[1] = (Button) add(no);
        bList[2] = (Button) add(maybe);

        // Register to receive action events.
        for(int i = 0; i < 3; i++) {
            bList[i].addActionListener(this);
        }

        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }
```
In this version, the program stores each button reference in an array when the buttons are added to the frame. (Recall that the `add()` method returns a reference to the button when it is added.) Inside `actionPerformed()`, this array is then used to determine which button has been pressed.

For simple programs, it is usually easier to recognize buttons by their labels. However, in situations in which you will be changing the label inside a button during the execution of your program, or using buttons that have the same label, it may be easier to determine which button has been pushed by using its object reference. It is also possible to set the action command string associated with a button to something other than its label by calling `setActionCommand()`. This method changes the action command string, but does not affect the string used to label the button. Thus, setting the action command enables the action command and the label of a button to differ.

In some cases, you can handle the action events generated by a button (or some other type of control) by use of an anonymous inner class (as described in Chapter 24) or a lambda expression (discussed in Chapter 15). For example, assuming the previous programs, here is a set of action event handlers that use lambda expressions:
// Use lambda expressions to handle action events
yes.addActionListener((ae) -> {
    msg = "You pressed " + ae.getActionCommand();
    repaint();
});

no.addActionListener((ae) -> {
    msg = "You pressed " + ae.getActionCommand();
    repaint();
});

maybe.addActionListener((ae) -> {
    msg = "You pressed " + ae.getActionCommand();
    repaint();
});

This code works because ActionListener defines a functional interface, which is
an interface with exactly one abstract method. Thus, it can be used by a lambda
expression. In general, you can use a lambda expression to handle an AWT event
when its listener defines a functional interface. For example, ItemListener is also a
functional interface. Of course, whether you use the traditional approach, an
anonymous inner class, or a lambda expression will be determined by the precise
nature of your application.

Applying Check Boxes
A check box is a control that is used to turn an option on or off. It consists of a small
box that can either contain a check mark or not. There is a label associated with each
check box that describes what option the box represents. You change the state of a
check box by clicking on it. Check boxes can be used individually or as part of a
group. Check boxes are objects of the Checkbox class.

Checkbox supports these constructors:

Checkbox() throws HeadlessException
Checkbox(String str) throws HeadlessException
Checkbox(String str, boolean on) throws HeadlessException
Checkbox(String str, boolean on, CheckboxGroup cbGroup) throws
HeadlessException
Checkbox(String str, CheckboxGroup cbGroup, boolean on) throws
HeadlessException
The first form creates a check box whose label is initially blank. The state of the check box is unchecked. The second form creates a check box whose label is specified by \( str \). The state of the check box is unchecked. The third form allows you to set the initial state of the check box. If \( on \) is \textbf{true}, the check box is initially checked; otherwise, it is cleared. The fourth and fifth forms create a check box whose label is specified by \( str \) and whose group is specified by \( cbGroup \). If this check box is not part of a group, then \( cbGroup \) must be \textbf{null}. (Check box groups are described in the next section.) The value of \( on \) determines the initial state of the check box.

To retrieve the current state of a check box, call \texttt{getState( )}. To set its state, call \texttt{setState( )}. You can obtain the current label associated with a check box by calling \texttt{getLabel( )}. To set the label, call \texttt{setLabel( )}. These methods are as follows:

\begin{verbatim}
  boolean getState( )
  void setState(boolean on)
  String getLabel( )
  void setLabel(String str)
\end{verbatim}

Here, if \( on \) is \textbf{true}, the box is checked. If it is \textbf{false}, the box is cleared. The string passed in \( str \) becomes the new label associated with the invoking check box.

**Handling Check Boxes**

Each time a check box is selected or deselected, an item event is generated. This is sent to any listeners that previously registered an interest in receiving item event notifications from that component. Each listener implements the \texttt{ItemListener} interface. That interface defines the \texttt{itemStateChanged( )} method. An \texttt{ItemEvent} object is supplied as the argument to this method. It contains information about the event (for example, whether it was a selection or deselection).

The following program creates four check boxes. The initial state of the first box is checked. The status of each check box is displayed. Each time you change the state of a check box, the status display is updated.
// Demonstrate check boxes.
import java.awt.*;
import java.awt.event.*;

public class CheckboxDemo extends Frame implements ItemListener {
    String msg = ""
    Checkbox windows, android, solaris, mac;

    public CheckboxDemo() {

        // Use a flow layout.
        setLayout(new FlowLayout());

        // Create check boxes.
        windows = new Checkbox("Windows", true);
        android = new Checkbox("Android");
        solaris = new Checkbox("Solaris");
        mac = new Checkbox("Mac OS");

        // Add the check boxes to the frame.
        add(windows);
        add(android);
        add(solaris);
        add(mac);

        // Add item listeners.
        windows.addItemListener(this);
        android.addItemListener(this);
        solaris.addItemListener(this);
        mac.addItemListener(this);

        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });

    }

    public void itemStateChanged(ItemEvent ie) {
        repaint();
    }
}
Sample output is shown in Figure 26-2.

Figure 26-2 Sample output from the CheckboxDemo program

CheckboxGroup

It is possible to create a set of mutually exclusive check boxes in which one and only one check box in the group can be checked at any one time. These check boxes are
often called radio buttons, because they act like the station selector on a car radio—only one station can be selected at any one time. To create a set of mutually exclusive check boxes, you must first define the group to which they will belong and then specify that group when you construct the check boxes. Check box groups are objects of type CheckboxGroup. Only the default constructor is defined, which creates an empty group.

You can determine which check box in a group is currently selected by calling getSelectedCheckbox(). You can set a check box by calling setSelectedCheckbox(). These methods are as follows:

```java
Checkbox getSelectedCheckbox()
void setSelectedCheckbox(Checkbox which)
```

Here, which is the check box that you want to be selected. The previously selected check box will be turned off.

Here is a program that uses check boxes that are part of a group:

```java
// Demonstrate check box group.
import java.awt.*;
import java.awt.event.*;

public class CBGroup extends Frame implements ItemListener {
    String msg = "";
    Checkbox windows, android, solaris, mac;
    CheckboxGroup cbg;

    public CBGroup() {
        // Use a flow layout.
        setLayout(new FlowLayout());

        // Create a check box group.
        cbg = new CheckboxGroup();
```
// Create the check boxes and include them in the group.
windows = new Checkbox("Windows", cbg, true);
android = new Checkbox("Android", cbg, false);
solaris = new Checkbox("Solaris", cbg, false);
mac = new Checkbox("Mac OS", cbg, false);

// Add the check boxes to the frame.
add(windows);
add(android);
add(solaris);
add(mac);

// Add item listeners.
windows.addItemSelectedListener(this);
android.addItemSelectedListener(this);
solaris.addItemSelectedListener(this);
mac.addItemSelectedListener(this);

addWindowListener(new WindowAdapter() {
    public void windowClosing(WindowEvent we) {
        System.exit(0);
    }
});
Sample output generated by the CBGroup program is shown in Figure 26-3. Notice that the check boxes are now circular in shape.

![CBGroup Program Output](image_url)

**Figure 26-3** Sample output from the CBGroup program

### Choice Controls

The Choice class is used to create a *pop-up list* of items from which the user may choose. Thus, a Choice control is a form of menu. When inactive, a Choice component takes up only enough space to show the currently selected item. When the user clicks on it, the whole list of choices pops up, and a new selection can be made. Each item in the list is a string that appears as a left-justified label in the order it is added to the Choice object. Choice defines only the default constructor, which creates an empty list.
To add a selection to the list, call `add()`. It has this general form:

```java
void add(String name)
```

Here, `name` is the name of the item being added. Items are added to the list in the order in which calls to `add()` occur.

To determine which item is currently selected, you may call either `getSelectedItem()` or `getSelectedIndex()`. These methods are shown here:

```java
String getSelectedItem()
int getSelectedIndex()
```

The `getSelectedItem()` method returns a string containing the name of the item. `getSelectedIndex()` returns the index of the item. The first item is at index 0. By default, the first item added to the list is selected.

To obtain the number of items in the list, call `getItemCount()`. You can set the currently selected item using the `select()` method with either a zero-based integer index or a string that will match a name in the list. These methods are shown here:

```java
int getItemCount()
void select(int index)
void select(String name)
```

Given an index, you can obtain the name associated with the item at that index by calling `getItem()`, which has this general form:

```java
String getItem(int index)
```

Here, `index` specifies the index of the desired item.

### Handling Choice Lists

Each time a choice is selected, an item event is generated. This is sent to any listeners that previously registered an interest in receiving item event notifications from that component. Each listener implements the `ItemListener` interface. That interface defines the `itemStateChanged()` method. An `ItemEvent` object is supplied as the argument to this method.

Here is an example that creates two `Choice` menus. One selects the operating system. The other selects the browser.
// Demonstrate Choice lists.
import java.awt.*;
import java.awt.event.*;

public class ChoiceDemo extends Frame implements ItemListener {
    Choice os, browser;
    String msg = "";

    public ChoiceDemo() {

        // Use a flow layout.
        setLayout(new FlowLayout());

        // Create choice lists.
        os = new Choice();
        browser = new Choice();

        // Add items to os list.
        os.add("Windows");
        os.add("Android");
        os.add("Solaris");
        os.add("Mac OS");

        // Add items to browser list.
        browser.add("Internet Explorer");
        browser.add("Firefox");
        browser.add("Chrome");

        // Add choice lists to window.
        add(os);
        add(browser);

        // Add item listeners.
        os.addItemListener(this);
        browser.addItemListener(this);

        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }
}
public void itemStateChanged(ItemEvent ie) {
    repaint();
}

// Display current selections.
public void paint(Graphics g) {
    msg = "Current OS: ";
    msg += os.getSelectedItem();
    g.drawString(msg, 20, 120);
    msg = "Current Browser: ";
    msg += browser.getSelectedItem();
    g.drawString(msg, 20, 140);
}

public static void main(String[] args) {
    ChoiceDemo appwin = new ChoiceDemo();

    appwin.setSize(new Dimension(240, 180));
    appwin.setTitle("ChoiceDemo");
    appwin.setVisible(true);
}

Sample output is shown in Figure 26-4.

![Figure 26-4](image)

**Figure 26-4** Sample output from the **ChoiceDemo** program

**Using Lists**

The **List** class provides a compact, multiple-choice, scrolling selection list. Unlike the **Choice** object, which shows only the single selected item in the menu, a **List** object can be constructed to show any number of choices in the visible window. It can also be created to allow multiple selections. **List** provides these constructors:
List( ) throws HeadlessException
List(int numRows) throws HeadlessException
List(int numRows, boolean multipleSelect) throws HeadlessException

The first version creates a List control that allows only one item to be selected at any one time. In the second form, the value of numRows specifies the number of entries in the list that will always be visible (others can be scrolled into view as needed). In the third form, if multipleSelect is true, then the user may select two or more items at a time. If it is false, then only one item may be selected.

To add a selection to the list, call add( ). It has the following two forms:

```java
void add(String name)
void add(String name, int index)
```

Here, name is the name of the item added to the list. The first form adds items to the end of the list. The second form adds the item at the index specified by index. Indexing begins at zero. You can specify –1 to add the item to the end of the list.

For lists that allow only single selection, you can determine which item is currently selected by calling either getSelectedItem( ) or getSelectedIndex( ). These methods are shown here:

```java
String getSelectedItem( )
int getSelectedIndex( )
```

The getSelectedItem( ) method returns a string containing the name of the item. If more than one item is selected, or if no selection has yet been made, null is returned. getSelectedIndex( ) returns the index of the item. The first item is at index 0. If more than one item is selected, or if no selection has yet been made, –1 is returned.

For lists that allow multiple selection, you must use either getSelectedItems( ) or getSelectedIndexes( ), shown here, to determine the current selections:

```java
String[ ] getSelectedItems( )
int[ ] getSelectedIndexes( )
```

getSelectedItems( ) returns an array containing the names of the currently selected items. getSelectedIndexes( ) returns an array containing the indexes of the currently selected items.

To obtain the number of items in the list, call getItemCount( ). You can set the currently selected item by using the select( ) method with a zero-based integer index.
These methods are shown here:

```java
int getItemCount()
void select(int index)
```

Given an index, you can obtain the name associated with the item at that index by calling `getItem()`, which has this general form:

```java
String getItem(int index)
```

Here, `index` specifies the index of the desired item.

## Handling Lists

To process list events, you will need to implement the `ActionListener` interface. Each time a `List` item is double-clicked, an `ActionEvent` object is generated. Its `getActionCommand()` method can be used to retrieve the name of the newly selected item. Also, each time an item is selected or deselected with a single click, an `ItemEvent` object is generated. Its `getStateChange()` method can be used to determine whether a selection or deselection triggered this event. `getItemSelectable()` returns a reference to the object that triggered this event.

Here is an example that converts the `Choice` controls in the preceding section into `List` components, one multiple choice and the other single choice:
// Demonstrate Lists.
import java.awt.*;
import java.awt.event.*;

public class ListDemo extends Frame implements ActionListener {
    List os, browser;
    String msg = "";

    public ListDemo() {

        // Use a flow layout.
        setLayout(new FlowLayout());

        // Create a multi-selection list.
        os = new List(4, true);

        // Create a single-selection list.
        browser = new List(4);

        // Add items to os list.
        os.add("Windows");
    }
}
os.add("Android");
os.add("Solaris");
os.add("Mac OS");

// Add items to browser list.
browser.add("Internet Explorer");
browser.add("Firefox");
browser.add("Chrome");

// Make initial selections.
browser.select(1);
os.select(0);

// Add lists to the frame.
add(os);
add(browser);

// Add action listeners.
os.addActionListener(this);
browser.addActionListener(this);

addListener(new WindowAdapter() {
    public void windowClosing(WindowEvent we) {
        System.exit(0);
    }
});
public void actionPerformed(ActionEvent ae) {
    repaint();
}

// Display current selections.
public void paint(Graphics g) {
    int idx[];

    msg = "Current OS: ";
    idx = os.getSelectedIndexes();
    for(int i=0; i<idx.length; i++)
        msg += os.getItem(idx[i]) + " ";
    g.drawString(msg, 6, 120);
    msg = "Current Browser: ";
    msg += browser.getSelectedItem();
    g.drawString(msg, 6, 140);
}

public static void main(String[] args) {
    ListDemo appwin = new ListDemo();

    appwin.setSize(new Dimension(300, 180));
    appwin.setTitle("ListDemo");
    appwin.setVisible(true);
}

Sample output generated by the **ListDemo** program is shown in **Figure 26-5**.

![ListDemo](image)

**Figure 26-5**  Sample output from the **ListDemo** program

**Managing Scroll Bars**

*Scroll bars* are used to select continuous values between a specified minimum and
maximum. Scroll bars may be oriented horizontally or vertically. A scroll bar is actually a composite of several individual parts. Each end has an arrow that you can click to move the current value of the scroll bar one unit in the direction of the arrow. The current value of the scroll bar relative to its minimum and maximum values is indicated by the slider box (or thumb) for the scroll bar. The slider box can be dragged by the user to a new position. The scroll bar will then reflect this value. In the background space on either side of the thumb, the user can click to cause the thumb to jump in that direction by some increment larger than 1. Typically, this action translates into some form of page up and page down. Scroll bars are encapsulated by the Scrollbar class.

Scrollbar defines the following constructors:

Scrollbar( ) throws HeadlessException
Scrollbar(int style) throws HeadlessException
Scrollbar(int style, int initialValue, int thumbSize, int min, int max) throws HeadlessException

The first form creates a vertical scroll bar. The second and third forms allow you to specify the orientation of the scroll bar. If style is Scrollbar.VERTICAL, a vertical scroll bar is created. If style is Scrollbar.HORIZONTAL, the scroll bar is horizontal. In the third form of the constructor, the initial value of the scroll bar is passed in initialValue. The number of units represented by the height of the thumb is passed in thumbSize. The minimum and maximum values for the scroll bar are specified by min and max.

If you construct a scroll bar by using one of the first two constructors, then you need to set its parameters by using setValues( ), shown here, before it can be used:

void setValues(int initialValue, int thumbSize, int min, int max)

The parameters have the same meaning as they have in the third constructor just described.

To obtain the current value of the scroll bar, call getValue( ). It returns the current setting. To set the current value, call setValue( ). These methods are as follows:

int getValue( )
void setValue(int newValue)

Here, newValue specifies the new value for the scroll bar. When you set a value, the slider box inside the scroll bar will be positioned to reflect the new value.

You can also retrieve the minimum and maximum values via getMinimum( ) and
getMinimum(), shown here:

```
int getMinimum()
int getMaximum()
```

They return the requested quantity.

By default, 1 is the increment added to or subtracted from the scroll bar each time it is scrolled up or down one line. You can change this increment by calling setUnitIncrement(). By default, page-up and page-down increments are 10. You can change this value by calling setBlockIncrement(). These methods are shown here:

```
void setUnitIncrement(int newIncr)
void setBlockIncrement(int newIncr)
```

**Handling Scroll Bars**

To process scroll bar events, you need to implement the AdjustmentListener interface. Each time a user interacts with a scroll bar, an AdjustmentEvent object is generated. Its getAdjustmentType() method can be used to determine the type of the adjustment. The types of adjustment events are as follows:

<table>
<thead>
<tr>
<th>Adjustment Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLOCK_DECREMENT</td>
<td>A page-down event has been generated.</td>
</tr>
<tr>
<td>BLOCK_INCREMENT</td>
<td>A page-up event has been generated.</td>
</tr>
<tr>
<td>TRACK</td>
<td>An absolute tracking event has been generated.</td>
</tr>
<tr>
<td>UNIT_DECREMENT</td>
<td>The line-down button in a scroll bar has been pressed.</td>
</tr>
<tr>
<td>UNIT_INCREMENT</td>
<td>The line-up button in a scroll bar has been pressed.</td>
</tr>
</tbody>
</table>

The following example creates both a vertical and a horizontal scroll bar. The current settings of the scroll bars are displayed. If you drag the mouse while inside the window, the coordinates of each drag event are used to update the scroll bars. An asterisk is displayed at the current drag position. Notice the use of setPreferredSize() to set the size of the scrollbars.
// Demonstrate scroll bars.
import java.awt.*;
import java.awt.event.*;

public class SBDemo extends Frame
    implements AdjustmentListener {

    String msg = "";
    Scrollbar vertSB, horzSB;

    public SBDemo() {

        // Use a flow layout.
        setLayout(new FlowLayout());

        // Create scroll bars and set preferred size.
        vertSB = new Scrollbar(Scrollbar.VERTICAL,
                                0, 1, 0, 200);
        vertSB.setPreferredSize(new Dimension(20, 100));

        horzSB = new Scrollbar(Scrollbar.HORIZONTAL,
                               0, 1, 0, 100);
        horzSB.setPreferredSize(new Dimension(100, 20));

        // Add the scroll bars to the frame.
        add(vertSB);
        add(horzSB);

        // Add AdjustmentListeners for the scroll bars.
        vertSB.addAdjustmentListener(this);
        horzSB.addAdjustmentListener(this);

        // Add MouseMotionListener.
        addMouseMotionListener(new MouseAdapter() {
             // Update scroll bars to reflect mouse dragging.
             public void mouseDragged(MouseEvent me) {
                 int x = me.getX();
                 int y = me.getY();
                 vertSB.setValue(y);
                 horzSB.setValue(x);
                 repaint();
             }
         });
    }
```java
addWindowListener(new WindowAdapter() {
    public void windowClosing(WindowEvent we) {
        System.exit(0);
    }
});

public void adjustmentValueChanged(AdjustmentEvent ae) {
    repaint();
}

// Display current value of scroll bars.
public void paint(Graphics g) {
    msg = "Vertical: " + vertSB.getValue();
    msg += ", Horizontal: " + horzSB.getValue();
    g.drawString(msg, 20, 160);

    // show current mouse drag position
    g.drawString("*", horzSB.getValue(),
                vertSB.getValue());
}

public static void main(String[] args) {
    SBDemo appwin = new SBDemo();

    appwin.setSize(new Dimension(300, 180));
    appwin.setTitle("SBDemo");
    appwin.setVisible(true);
}
```

Sample output from the **SBDemo** program is shown in Figure 26-6.

![Figure 26-6](image-url)
Using a TextField

The `TextField` class implements a single-line text-entry area, usually called an *edit control*. Text fields allow the user to enter strings and to edit the text using the arrow keys, cut and paste keys, and mouse selections. `TextField` is a subclass of `TextComponent`. `TextField` defines the following constructors:

- `TextField()` throws HeadlessException
- `TextField(int numChars)` throws HeadlessException
- `TextField(String str)` throws HeadlessException
- `TextField(String str, int numChars)` throws HeadlessException

The first version creates a default text field. The second form creates a text field that is `numChars` characters wide. The third form initializes the text field with the string contained in `str`. The fourth form initializes a text field and sets its width.

`TextField` (and its superclass `TextComponent`) provides several methods that allow you to utilize a text field. To obtain the string currently contained in the text field, call `getText()`. To set the text, call `setText()`. These methods are as follows:

- `String getText()`
- `void setText(String str)`

Here, `str` is the new string.

The user can select a portion of the text in a text field. Also, you can select a portion of text under program control by using `select()`. Your program can obtain the currently selected text by calling `getSelectedText()`. These methods are shown here:

- `String getSelectedText()`
- `void select(int startIndex, int endIndex)`

`getSelectedText()` returns the selected text. The `select()` method selects the characters beginning at `startIndex` and ending at `endIndex` –1.

You can control whether the contents of a text field may be modified by the user by calling `setEditable()`. You can determine editability by calling `isEditable()`. These methods are shown here:

- `boolean isEditable()`
- `void setEditable(boolean canEdit)`
isEditable() returns true if the text may be changed and false if not. In setEditable(), if canEdit is true, the text may be changed. If it is false, the text cannot be altered.

There may be times when you will want the user to enter text that is not displayed, such as a password. You can disable the echoing of the characters as they are typed by calling setEchoChar(). This method specifies a single character that the TextField will display when characters are entered (thus, the actual characters typed will not be shown). You can check a text field to see if it is in this mode with the echoCharIsSet() method. You can retrieve the echo character by calling the getEchoChar() method. These methods are as follows:

```java
void setEchoChar(char ch)
boolean echoCharIsSet()
char getEchoChar()
```

Here, ch specifies the character to be echoed. If ch is zero, then normal echoing is restored.

**Handling a TextField**

Since text fields perform their own editing functions, your program generally will not respond to individual key events that occur within a text field. However, you may want to respond when the user presses enter. When this occurs, an action event is generated.

Here is an example that creates the classic user name and password screen:
// Demonstrate text field.
import java.awt.*;
import java.awt.event.*;

public class TextFieldDemo extends Frame
    implements ActionListener {

    TextField name, pass;

    public TextFieldDemo() {

        // Use a flow layout.
        setLayout(new FlowLayout());

        // Create controls.
        Label namep = new Label("Name: ", Label.RIGHT);
        Label passp = new Label("Password: ", Label.RIGHT);
        name = new TextField(12);
        pass = new TextField(8);
        pass.setEchoChar('?');
    }
// Add the controls to the frame.
add(namep);
add(name);
add(passp);
add(pass);

// Add action event handlers.
name.addActionListener(this);
pass.addActionListener(this);

addWindowListener(new WindowAdapter() {
    public void windowClosing(WindowEvent we) {
        System.exit(0);
    }
});

// User pressed Enter.
public void actionPerformed(ActionEvent ae) {
    repaint();
}

public void paint(Graphics g) {
    g.drawString("Name: " + name.getText(), 20, 100);
    g.drawString("Selected text in name: "
            + name.getSelectedText(), 20, 120);
    g.drawString("Password: " + pass.getText(), 20, 140);
}

public static void main(String[] args) {
    TextFieldDemo appwin = new TextFieldDemo();

    appwin.setSize(new Dimension(380, 180));
    appwin.setTitle("TextFieldDemo");
    appwin.setVisible(true);
}

Sample output from the TextFieldDemo program is shown in Figure 26-7.
Figure 26-7  Sample output from the TextFieldDemo program

Using a TextArea

Sometimes a single line of text input is not enough for a given task. To handle these situations, the AWT includes a simple multiline editor called TextArea. Following are the constructors for TextArea:

- TextArea() throws HeadlessException
- TextArea(int numLines, int numChars) throws HeadlessException
- TextArea(String str) throws HeadlessException
- TextArea(String str, int numLines, int numChars) throws HeadlessException
- TextArea(String str, int numLines, int numChars, int sBars) throws HeadlessException

Here, numLines specifies the height, in lines, of the text area, and numChars specifies its width, in characters. Initial text can be specified by str. In the fifth form, you can specify the scroll bars that you want the control to have. sBars must be one of these values:

<table>
<thead>
<tr>
<th>SCROLLBARS_BOTH</th>
<th>SCROLLBARS_NONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCROLLBARS_HORIZONTAL_ONLY</td>
<td>SCROLLBARS_VERTICAL_ONLY</td>
</tr>
</tbody>
</table>

TextArea is a subclass of TextComponent. Therefore, it supports the getText(), setText(), getSelectedText(), select(), isEditable(), and setEditable() methods described in the preceding section.

TextArea adds the following editing methods:

- void append(String str)
- void insert(String str, int index)
void replaceRange(String str, int startIndex, int endIndex)

The append( ) method appends the string specified by str to the end of the current text. insert() inserts the string passed in str at the specified index. To replace text, call replaceRange(). It replaces the characters from startIndex to endIndex–1, with the replacement text passed in str.

Text areas are almost self-contained controls. Your program incurs virtually no management overhead. Normally, your program simply obtains the current text when it is needed. You can, however, listen for TextEvents, if you choose.

The following program creates a TextArea control:

    // Demonstrate TextArea.
    import java.awt.*;
    import java.awt.event.*;

    public class TextAreaDemo extends Frame {

        public TextAreaDemo() {

            // Use a flow layout.
            setLayout(new FlowLayout());
        }
String val = 
"Java 9 is the latest version of the most\n" + 
"widely-used computer language for Internet programming.\n" + 
"Building on a rich heritage, Java has advanced both\n" + 
"the art and science of computer language design.\n\n" + 
"One of the reasons for Java’s ongoing success is its\n" + 
"constant, steady rate of evolution. Java has never stood\n" + 
"still. Instead, Java has consistently adapted to the\n" + 
"rapidly changing landscape of the networked world.\n" + 
"Moreover, Java has often led the way, charting the\n" + 
"course for others to follow."

TextArea text = new TextArea(val, 10, 30);
add(text);

addWindowListener(new WindowAdapter() {
    public void windowClosing(WindowEvent we) {
        System.exit(0);
    }
});

public static void main(String[] args) {
    TextAreaDemo appwin = new TextAreaDemo();

    appwin.setSize(new Dimension(300, 220));
    appwin.setTitle("TextAreaDemo");
    appwin.setVisible(true);
}

Here is sample output from the TextAreaDemo program:
Understanding Layout Managers

All of the components that we have shown so far have been positioned by the `FlowLayout` layout manager. As we mentioned at the beginning of this chapter, a layout manager automatically arranges your controls within a window by using some type of algorithm. While it is possible to lay out Java controls by hand, you generally won’t want to, for two main reasons. First, it is very tedious to manually lay out a large number of components. Second, sometimes the width and height information is not yet available when you need to arrange some control, because the native toolkit components haven’t been realized. This is a chicken-and-egg situation; it is pretty confusing to figure out when it is okay to use the size of a given component to position it relative to another.

Each `Container` object has a layout manager associated with it. A layout manager is an instance of any class that implements the `LayoutManager` interface. The layout manager is set by the `setLayout()` method. If no call to `setLayout()` is made, then the default layout manager is used. Whenever a container is resized (or sized for the first time), the layout manager is used to position each of the components within it.

The `setLayout()` method has the following general form:

```
void setLayout(LayoutManager layoutObj)
```

Here, `layoutObj` is a reference to the desired layout manager. If you wish to disable the layout manager and position components manually, pass `null` for `layoutObj`. If you do this, you will need to determine the shape and position of each component manually, using the `setBounds()` method defined by `Component`. Normally, you will want to use a layout manager.

Each layout manager keeps track of a list of components that are stored by their names. The layout manager is notified each time you add a component to a container. Whenever the container needs to be resized, the layout manager is consulted via its `minimumLayoutSize()` and `preferredLayoutSize()` methods. Each component that is being managed by a layout manager contains the `getPreferredSize()` and `getMinimumSize()` methods. These return the preferred and minimum size required to display each component. The layout manager will honor these requests if at all possible, while maintaining the integrity of the layout policy. You may override these methods for controls that you subclass. Default values are provided otherwise.

Java has several predefined `LayoutManager` classes, several of which are described next. You can use the layout manager that best fits your application.
**FlowLayout**

You have already seen `FlowLayout` in action. It is the layout manager that the preceding examples have used. `FlowLayout` implements a simple layout style, which is similar to how words flow in a text editor. The direction of the layout is governed by the container’s component orientation property, which, by default, is left to right, top to bottom. Therefore, by default, components are laid out line-by-line beginning at the upper-left corner. In all cases, when a line is filled, layout advances to the next line. A small space is left between each component, above and below, as well as left and right. Here are the constructors for `FlowLayout`:

- `FlowLayout( )`
- `FlowLayout(int how)`
- `FlowLayout(int how, int horz, int vert)`

The first form creates the default layout, which centers components and leaves five pixels of space between each component. The second form lets you specify how each line is aligned. Valid values for `how` are as follows:

- `FlowLayout.LEFT`
- `FlowLayout.CENTER`
- `FlowLayout.RIGHT`
- `FlowLayout.LEADING`
- `FlowLayout.TRAILING`

These values specify left, center, right, leading edge, and trailing edge alignment, respectively. The third constructor allows you to specify the horizontal and vertical space left between components in `horz` and `vert`, respectively.

You can see the effect of specifying an alignment with `FlowLayout` by substituting this line in the `CheckboxDemo` program shown earlier:

```java
setLayout(new FlowLayout(FlowLayout.LEFT));
```

After making this change, the output will look like that shown here. Compare this with the original output, shown in Figure 26-2.
BorderLayout

The BorderLayout class implements a layout style that has four narrow, fixed-width components at the edges and one large area in the center. The four sides are referred to as north, south, east, and west. The middle area is called the center. BorderLayout is the default layout manager for Frame. Here are the constructors defined by BorderLayout:

```
BorderLayout( )
BorderLayout(int horz, int vert)
```

The first form creates a default border layout. The second allows you to specify the horizontal and vertical space left between components in `horz` and `vert`, respectively.

BorderLayout defines the following commonly used constants that specify the regions:

<table>
<thead>
<tr>
<th>BorderLayout.CENTER</th>
<th>BorderLayout.NORTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>BorderLayout.EAST</td>
<td>BorderLayout.SOUTH</td>
</tr>
<tr>
<td>BorderLayout.WEST</td>
<td></td>
</tr>
</tbody>
</table>

When adding components, you will use these constants with the following form of `add()`, which is defined by Container:

```
void add(Component compRef, Object region)
```

Here, `compRef` is a reference to the component to be added, and `region` specifies where the component will be added.

Here is an example of a BorderLayout with a component in each layout area:
// Demonstrate BorderLayout.
import java.awt.*;
import java.awt.event.*;

public class BorderLayoutDemo extends Frame {
    public BorderLayoutDemo() {

        // Here, BorderLayout is used by default.
        add(new Button("This is across the top."), BorderLayout.NORTH);
        add(new Label("The footer message might go here."), BorderLayout.SOUTH);
        add(new Button("Right"), BorderLayout.EAST);
        add(new Button("Left"), BorderLayout.WEST);

        String msg = "The reasonable man adapts " +
                    "himself to the world;\n" +
                    "the unreasonable one persists in " +
                    "trying to adapt the world to himself.\n" +
                    "Therefore all progress depends " +
                    "on the unreasonable man.\n" +
                    " - George Bernard Shaw\n";

        add(new TextArea(msg), BorderLayout.CENTER);

        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }
}

public static void main(String[] args) {
    BorderLayoutDemo appwin = new BorderLayoutDemo();

    appwin.setSize(new Dimension(300, 220));
    appwin.setTitle("BorderLayoutDemo");
    appwin.setVisible(true);
}

Sample output from the BorderLayoutDemo program is shown here:
Using Insets

Sometimes you will want to leave a small amount of space between the container that holds your components and the window that contains it. To do this, override the `getInsets()` method that is defined by `Container`. This method returns an `Insets` object that contains the top, bottom, left, and right inset to be used when the container is displayed. These values are used by the layout manager to inset the components when it lays out the window. The constructor for `Insets` is shown here:

```
Insets(int top, int left, int bottom, int right)
```

The values passed in `top`, `left`, `bottom`, and `right` specify the amount of space between the container and its enclosing window.

The `getInsets()` method has this general form:

```
Insets getInsets()
```

When overriding this method, you must return a new `Insets` object that contains the inset spacing you desire.

Here is the preceding `BorderLayout` example modified so that it insets its components. The background color has been set to cyan to help make the insets more visible.
// Demonstrate BorderLayout with insets.
import java.awt.*;
import java.awt.event.*;

public class InsetsDemo extends Frame {

    public InsetsDemo() {
        // Here, BorderLayout is used by default.

        // set background color so insets can be easily seen
        setBackground(Color.cyan);

        setLayout(new BorderLayout());
    }
}
add(new Button("This is across the top."), BorderLayout.NORTH);
add(new Label("The footer message might go here."), BorderLayout.SOUTH);
add(new Button("Right"), BorderLayout.EAST);
add(new Button("Left"), BorderLayout.WEST);

String msg = "The reasonable man adapts " + 
"himself to the world;\n" + 
"the unreasonable one persists in " + 
"trying to adapt the world to himself.\n" + 
"Therefore all progress depends " + 
"on the unreasonable man.\n\n" + 
" - George Bernard Shaw\n\n";

add(new TextArea(msg), BorderLayout.CENTER);

addWindowListener(new WindowAdapter() {
    public void windowClosing(WindowEvent we) {
        System.exit(0);
    }
});

// Override getInsets to add inset values.
public Insets getInsets() {
    return new Insets(40, 20, 10, 20);
}

public static void main(String[] args) {
    InsetsDemo appwin = new InsetsDemo();

    appwin.setSize(new Dimension(300, 220));
    appwin.setTitle("InsetsDemo");
    appwin.setVisible(true);
}

Sample output from the InsetsDemo program is shown here:
GridLayout

GridLayout lays out components in a two-dimensional grid. When you instantiate a
GridLayout, you define the number of rows and columns. The constructors
supported by GridLayout are shown here:

    GridLayout( )
    GridLayout(int numRows, int numColumns)
    GridLayout(int numRows, int numColumns, int horz, int vert)

The first form creates a single-column grid layout. The second form creates a grid
layout with the specified number of rows and columns. The third form allows you to
specify the horizontal and vertical space left between components in horz and vert,
respectively. Either numRows or numColumns can be zero. Specifying numRows as
zero allows for unlimited-length columns. Specifying numColumns as zero allows
for unlimited-length rows.

Here is a sample program that creates a 4×4 grid and fills it in with 15 buttons,
each labeled with its index:
// Demonstrate GridLayout
import java.awt.*;
import java.awt.event.*;

public class GridLayoutDemo extends Frame {
    static final int n = 4;

    public GridLayoutDemo() {

        // Use GridLayout.
        setLayout(new GridLayout(n, n));

        setFont(new Font("SansSerif", Font.BOLD, 24));

        for(int i = 0; i < n; i++) {
            for(int j = 0; j < n; j++) {
                int k = i * n + j;
                if(k > 0)
                    add(new Button("" + k));
            }
        }

        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }

    public static void main(String[] args) {
        GridLayoutDemo appwin = new GridLayoutDemo();

        appwin.setSize(new Dimension(300, 220));
        appwin.setTitle("GridLayoutDemo");
        appwin.setVisible(true);
    }

    Following is sample output generated by the GridLayoutDemo program:
TIP You might try using this example as the starting point for a 15-square puzzle.

### CardLayout

The `CardLayout` class is unique among the other layout managers in that it stores several different layouts. Each layout can be thought of as being on a separate index card in a deck that can be shuffled so that any card is on top at a given time. This can be useful for user interfaces with optional components that can be dynamically enabled and disabled upon user input. You can prepare the other layouts and have them hidden, ready to be activated when needed.

`CardLayout` provides these two constructors:

```java
CardLayout()
CardLayout(int horz, int vert)
```

The first form creates a default card layout. The second form allows you to specify the horizontal and vertical space left between components in `horz` and `vert`, respectively.

Use of a card layout requires a bit more work than the other layouts. The cards are typically held in an object of type `Panel`. This panel must have `CardLayout` selected as its layout manager. The cards that form the deck are also typically objects of type `Panel`. Thus, you must create a panel that contains the deck and a panel for each card in the deck. Next, you add to the appropriate panel the components that form each card. You then add these panels to the panel for which `CardLayout` is the layout manager. Finally, you add this panel to the window. Once these steps are complete, you must provide some way for the user to select between cards. One common approach is to include one push button for each card in the deck.

When card panels are added to a panel, they are usually given a name. One way to do this is to use this form of `add( )` when adding cards to a panel:
void add(Component panelRef, Object name)

Here, name is a string that specifies the name of the card whose panel is specified by panelRef.

After you have created a deck, your program activates a card by calling one of the following methods defined by CardLayout:

void first(Container deck)
void last(Container deck)
void next(Container deck)
void previous(Container deck)
void show(Container deck, String cardName)

Here, deck is a reference to the container (usually a panel) that holds the cards, and cardName is the name of a card. Calling first() causes the first card in the deck to be shown. To show the last card, call last(). To show the next card, call next(). To show the previous card, call previous(). Both next() and previous() automatically cycle back to the top or bottom of the deck, respectively. The show() method displays the card whose name is passed in cardName.

The following example creates a two-level card deck that allows the user to select an operating system. Windows-based operating systems are displayed in one card. Mac OS, Android, and Solaris are displayed in the other card.
// Demonstrate CardLayout.
import java.awt.*;
import java.awt.event.*;

public class CardLayoutDemo extends Frame {

  Checkbox windows10, windows7, windows8, android, solaris, mac;
  Panel osCards;
  CardLayout cardLO;
  Button Win, Other;

  public CardLayoutDemo() {

    // Use a flow layout for the main frame.
    setLayout(new FlowLayout());

    Win = new Button("Windows");
    Other = new Button("Other");
    add(Win);
    add(Other);

    // Set osCards panel to use CardLayout.
    cardLO = new CardLayout();
    osCards = new Panel();
    osCards.setLayout(cardLO);

    windows7 = new Checkbox("Windows 7", true);
    windows8 = new Checkbox("Windows 8");
windows10 = new Checkbox("Windows 10");
android = new Checkbox("Android");
solaris = new Checkbox("Solaris");
mac = new Checkbox("Mac OS");

    // Add Windows check boxes to a panel.
Panel winPan = new Panel();
winPan.add(windows7);
winPan.add(windows8);
winPan.add(windows10);

    // Add other OS check boxes to a panel.
Panel otherPan = new Panel();
otherPan.add(android);
otherPan.add(solaris);
otherPan.add(mac);

    // Add panels to card deck panel.
osCards.add(winPan, "Windows");
osCards.add(otherPan, "Other");

    // Add cards to main frame panel.
add(osCards);

    // Use lambda expressions to handle button events.
Win.addActionListener((ae) -> cardLO.show(osCards, "Windows"));
Other.addActionListener((ae) -> cardLO.show(osCards, "Other"));
Here is sample output generated by the CardLayoutDemo program. Each card is activated by pushing its button. You can also cycle through the cards by clicking the mouse.

GridBagLayout
Although the preceding layouts are perfectly acceptable for many uses, some
situations will require that you take a bit more control over how the components are arranged. A good way to do this is to use a grid bag layout, which is specified by the `GridBagLayout` class. What makes the grid bag useful is that you can specify the relative placement of components by specifying their positions within cells inside a grid. The key to the grid bag is that each component can be a different size, and each row in the grid can have a different number of columns. This is why the layout is called a *grid bag*. It’s a collection of small grids joined together.

The location and size of each component in a grid bag are determined by a set of constraints linked to it. The constraints are contained in an object of type `GridBagConstraints`. Constraints include the height and width of a cell, and the placement of a component, its alignment, and its anchor point within the cell.

The general procedure for using a grid bag is to first create a new `GridBagLayout` object and to make it the current layout manager. Then, set the constraints that apply to each component that will be added to the grid bag. Finally, add the components to the layout manager. Although `GridBagLayout` is a bit more complicated than the other layout managers, it is still quite easy to use once you understand how it works.

`GridBagLayout` defines only one constructor, which is shown here:

```java
GridBagLayout( )
```

`GridBagLayout` defines several methods, of which many are protected and not for general use. There is one method, however, that you must use: `setConstraints( )`. It is shown here:

```java
void setConstraints(Component comp, GridBagConstraints cons)
```

Here, `comp` is the component for which the constraints specified by `cons` apply. This method sets the constraints that apply to each component in the grid bag.

The key to successfully using `GridBagLayout` is the proper setting of the constraints, which are stored in a `GridBagConstraints` object. `GridBagConstraints` defines several fields that you can set to govern the size, placement, and spacing of a component. These are shown in *Table 26-1*. Several are described in greater detail in the following discussion.
Table 26-1  Constraint Fields Defined by GridBagConstraints

<table>
<thead>
<tr>
<th>Field</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>int anchor</td>
<td>Specifies the location of a component within a cell. The default is GridBagConstraints.CENTER.</td>
</tr>
<tr>
<td>int fill</td>
<td>Specifies how a component is resized if the component is smaller than its cell. Valid values are GridBagConstraints.NONE (the default), GridBagConstraints.HORIZONTAL, GridBagConstraints.VERTICAL, GridBagConstraints.BOTH.</td>
</tr>
<tr>
<td>int gridheight</td>
<td>Specifies the height of component in terms of cells. The default is 1.</td>
</tr>
<tr>
<td>int gridwidth</td>
<td>Specifies the width of component in terms of cells. The default is 1.</td>
</tr>
<tr>
<td>int gridx</td>
<td>Specifies the X coordinate of the cell to which the component will be added. The default value is GridBagConstraints.RELATIVE.</td>
</tr>
<tr>
<td>int gridy</td>
<td>Specifies the Y coordinate of the cell to which the component will be added. The default value is GridBagConstraints.RELATIVE.</td>
</tr>
<tr>
<td>Insets insets</td>
<td>Specifies the insets. Default insets are all zero.</td>
</tr>
<tr>
<td>int ipadx</td>
<td>Specifies extra horizontal space that surrounds a component within a cell. The default is 0.</td>
</tr>
<tr>
<td>int ipady</td>
<td>Specifies extra vertical space that surrounds a component within a cell. The default is 0.</td>
</tr>
<tr>
<td>double weightx</td>
<td>Specifies a weight value that determines the horizontal spacing between cells and the edges of the container that holds them. The default value is 0.0. The greater the weight, the more space that is allocated. If all values are 0.0, extra space is distributed evenly between the edges of the window.</td>
</tr>
<tr>
<td>double weighty</td>
<td>Specifies a weight value that determines the vertical spacing between cells and the edges of the container that holds them. The default value is 0.0. The greater the weight, the more space that is allocated. If all values are 0.0, extra space is distributed evenly between the edges of the window.</td>
</tr>
</tbody>
</table>

**GridBagConstraints** also defines several static fields that contain standard constraint values, such as GridBagConstraints.CENTER and GridBagConstraints.VERTICAL.

When a component is smaller than its cell, you can use the anchor field to specify where within the cell the component’s top-left corner will be located. There are three types of values that you can give to anchor. The first are absolute:
As their names imply, these values cause the component to be placed at the specific locations.

The second type of values that can be given to anchor is relative, which means the values are relative to the container’s orientation, which might differ for non-Western languages. The relative values are shown here:

<table>
<thead>
<tr>
<th>GridBagConstraints.CENTER</th>
<th>GridBagConstraints.SOUTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>GridBagConstraints.EAST</td>
<td>GridBagConstraints.SOUTHEAST</td>
</tr>
<tr>
<td>GridBagConstraints.NORTH</td>
<td>GridBagConstraints.SOUTHWEST</td>
</tr>
<tr>
<td>GridBagConstraints.NORTHEAST</td>
<td>GridBagConstraints.WEST</td>
</tr>
<tr>
<td>GridBagConstraints.NORTHWEST</td>
<td></td>
</tr>
</tbody>
</table>

Their names describe the placement.

The third type of values that can be given to anchor allows you to position components relative to the baseline of the row. These values are shown here:

<table>
<thead>
<tr>
<th>GridBagConstraints.BASLINE</th>
<th>GridBagConstraints.BASLINE_LEADING</th>
</tr>
</thead>
<tbody>
<tr>
<td>GridBagConstraints.BASLINE_TRAILING</td>
<td>GridBagConstraints.ABOVE_BASELINE</td>
</tr>
<tr>
<td>GridBagConstraints.ABOVE_BASELINE_LEADING</td>
<td>GridBagConstraints.ABOVE_BASELINE_TRAILING</td>
</tr>
<tr>
<td>GridBagConstraints.BELOW_BASELINE</td>
<td>GridBagConstraints.BELOW_BASELINE_LEADING</td>
</tr>
<tr>
<td>GridBagConstraints.BELOW_BASELINE_TRAILING</td>
<td></td>
</tr>
</tbody>
</table>

The horizontal position can be either centered, against the leading edge (LEADING), or against the trailing edge (TRAILING).

The weightx and weighty fields are both quite important and quite confusing at first glance. In general, their values determine how much of the extra space within a container is allocated to each row and column. By default, both these values are zero. When all values within a row or a column are zero, extra space is distributed evenly between the edges of the window. By increasing the weight, you increase that row or
column’s allocation of space proportional to the other rows or columns. The best way to understand how these values work is to experiment with them a bit.

The gridwidth variable lets you specify the width of a cell in terms of cell units. The default is 1. To specify that a component use the remaining space in a row, use GridBagConstraints.REMAINDER. To specify that a component use the next-to-last cell in a row, use GridBagConstraints.RELATIVE. The gridheight constraint works the same way, but in the vertical direction.

You can specify a padding value that will be used to increase the minimum size of a cell. To pad horizontally, assign a value to ipadx. To pad vertically, assign a value to ipady.

Here is an example that uses GridBagLayout to demonstrate several of the points just discussed:

```java
// Use GridBagLayout.
import java.awt.*;
import java.awt.event.*;

public class GridBagDemo extends Frame
    implements ItemListener {

    String msg = "";
    Checkbox windows, android, solaris, mac;

    public GridBagDemo() {

        // Use a GridBagLayout
        GridBagLayout gbag = new GridBagLayout();
        GridBagConstraints gbc = new GridBagConstraints();
        setLayout(gbag);

        // Define check boxes.
        windows = new Checkbox("Windows ", true);
        android = new Checkbox("Android");
        solaris = new Checkbox("Solaris");
        mac = new Checkbox("Mac OS");

        // Define the grid bag.

        // Use default row weight of 0 for first row.
        gbc.weightx = 1.0; // use a column weight of 1
        gbc.ipadx = 200; // pad by 200 units
        gbc.insets = new Insets(0, 6, 0, 0); // inset slightly from left
```
gbc.anchor = GridBagConstraints.NORTHEAST;

gbc.gridwidth = GridBagConstraints.RELATIVE;
gbag.setConstraints(windows, gbc);

// Give second row a weight of 1.
gbc.weighty = 1.0;

gbc.gridwidth = GridBagConstraints.RELATIVE;
gbag.setConstraints(solaris, gbc);

gbc.gridwidth = GridBagConstraints.REMAINDER;
gbag.setConstraints(mac, gbc);

// Add the components.
add(windows);
add(android);
add(solaris);
add(mac);

// Register to receive item events.
windows.addItemListener(this);
android.addItemListener(this);
solaris.addItemListener(this);
mac.addItemListener(this);
```java
addWindowListener(new WindowAdapter() {
    public void windowClosing(WindowEvent we) {
        System.exit(0);
    }
});

// Repaint when status of a check box changes.
public void itemStateChanged(ItemEvent ie) {
    repaint();
}

// Display current state of the check boxes.
public void paint(Graphics g) {
    msg = "Current state: ";
g.drawString(msg, 20, 100);
    msg = " Windows: " + windows.getState();
g.drawString(msg, 30, 120);
    msg = " Android: " + android.getState();
g.drawString(msg, 30, 140);
    msg = " Solaris: " + solaris.getState();
g.drawString(msg, 30, 160);
    msg = " Mac: " + mac.getState();
g.drawString(msg, 30, 180);
}

public static void main(String[] args) {
    GridBagDemo appwin = new GridBagDemo();

    appwin.setSize(new Dimension(250, 200));
    appwin.setTitle("GridBagDemo");
    appwin.setVisible(true);
}
```

Sample output produced by the program is shown here.
In this layout, the operating system check boxes are positioned in a 2×2 grid. Each cell has a horizontal padding of 200. Each component is inset slightly (by 6 units) from the left. The column weight is set to 1, which causes any extra horizontal space to be distributed evenly between the columns. The first row uses a default weight of 0; the second has a weight of 1. This means that any extra vertical space is added to the second row.

**GridBagLayout** is a powerful layout manager. It is worth taking some time to experiment with and explore. Once you understand what the various settings do, you can use **GridBagLayout** to position components with a high degree of precision.

### Menu Bars and Menus

A top-level window can have a menu bar associated with it. A menu bar displays a list of top-level menu choices. Each choice is associated with a drop-down menu. This concept is implemented in the AWT by the following classes: **MenuBar**, **Menu**, and **MenuItem**. In general, a menu bar contains one or more **Menu** objects. Each **Menu** object contains a list of **MenuItem** objects. Each **MenuItem** object represents something that can be selected by the user. Since **Menu** is a subclass of **MenuItem**, a hierarchy of nested submenus can be created. It is also possible to include checkable menu items. These are menu options of type **CheckboxMenuItem** and will have a check mark next to them when they are selected.

To create a menu bar, first create an instance of **MenuBar**. This class defines only the default constructor. Next, create instances of **Menu** that will define the selections displayed on the bar. Following are the constructors for **Menu**: 

- Menu( ) throws HeadlessException
- Menu(String *optionName*) throws HeadlessException
- Menu(String *optionName*, boolean *removable*) throws HeadlessException
Here, *optionName* specifies the name of the menu selection. If *removable* is **true**, the menu can be removed and allowed to float free. Otherwise, it will remain attached to the menu bar. (Removable menus are implementation-dependent.) The first form creates an empty menu.

Individual menu items are of type **MenuItem**. It defines these constructors:

- `MenuItem() throws HeadlessException`
- `MenuItem(String itemName) throws HeadlessException`
- `MenuItem(String itemName, MenuShortcut keyAccel) throws HeadlessException`

Here, *itemName* is the name shown in the menu, and *keyAccel* is the menu shortcut for this item.

You can disable or enable a menu item by using the `setEnabled( )` method. Its form is shown here:

```java
void setEnabled(boolean enabledFlag)
```

If the argument *enabledFlag* is **true**, the menu item is enabled. If **false**, the menu item is disabled.

You can determine an item’s status by calling `isEnabled( )`. This method is shown here:

```java
boolean isEnabled( )
```

`isEnabled( )` returns **true** if the menu item on which it is called is enabled. Otherwise, it returns **false**.

You can change the name of a menu item by calling `setLabel( )`. You can retrieve the current name by using `getLabel( )`. These methods are as follows:

```java
void setLabel(String newName)
String getLabel( )
```

Here, *newName* becomes the new name of the invoking menu item. `getLabel( )` returns the current name.

You can create a checkable menu item by using a subclass of **MenuItem** called **CheckboxMenuItem**. It has these constructors:

- `CheckboxMenuItem() throws HeadlessException`
- `CheckboxMenuItem(String itemName) throws HeadlessException`
- `CheckboxMenuItem(String itemName, boolean on) throws HeadlessException`
Here, *itemName* is the name shown in the menu. Checkable items operate as toggles. Each time one is selected, its state changes. In the first two forms, the checkable entry is unchecked. In the third form, if *on* is true, the checkable entry is initially checked. Otherwise, it is cleared.

You can obtain the status of a checkable item by calling `getState()`. You can set it to a known state by using `setState()`. These methods are shown here:

```java
boolean getState()
void setState(boolean checked)
```

If the item is checked, `getState()` returns true. Otherwise, it returns false. To check an item, pass true to `setState()`. To clear an item, pass false.

Once you have created a menu item, you must add the item to a `Menu` object by using `add()`, which has the following general form:

```java
MenuItem add(MenuItem item)
```

Here, *item* is the item being added. Items are added to a menu in the order in which the calls to `add()` take place. The *item* is returned.

Once you have added all items to a `Menu` object, you can add that object to the menu bar by using this version of `add()` defined by `MenuBar`:

```java
Menu add(Menu menu)
```

Here, *menu* is the menu being added. The *menu* is returned.

Menus generate events only when an item of type `MenuItem` or `CheckboxMenuItem` is selected. They do not generate events when a menu bar is accessed to display a drop-down menu, for example. Each time a menu item is selected, an `ActionEvent` object is generated. By default, the action command string is the name of the menu item. However, you can specify a different action command string by calling `setActionCommand()` on the menu item. Each time a check box menu item is checked or unchecked, an `ItemEvent` object is generated. Thus, you must implement the `ActionListener` and/or `ItemListener` interfaces in order to handle these menu events.

The `getItem()` method of `ItemEvent` returns a reference to the item that generated this event. The general form of this method is shown here:

```java
Object getItem()
```

Following is an example that adds a series of nested menus to a pop-up window.
The item selected is displayed in the window. The state of the two check box menu items is also displayed.

```java
// Illustrate menus.
import java.awt.*;
import java.awt.event.*;

class MenuDemo extends Frame {
    String msg = "";
    CheckboxMenuItem debug, test;

    public MenuDemo() {

        // Create menu bar and add it to frame.
        MenuBar mbar = new MenuBar();
        setMenuBar(mbar);

        // Create the menu items.
        Menu file = new Menu("File");
        MenuItem item1, item2, item3, item4, item5;
        file.add(item1 = new MenuItem("New..."));
        file.add(item2 = new MenuItem("Open..."));
        file.add(item3 = new MenuItem("Close"));
        file.add(item4 = new MenuItem("-"));
        file.add(item5 = new MenuItem("Quit..."));
        mbar.add(file);

        Menu edit = new Menu("Edit");
        MenuItem item6, item7, item8, item9;
        edit.add(item6 = new MenuItem("Cut"));
        edit.add(item7 = new MenuItem("Copy"));
        edit.add(item8 = new MenuItem("Paste"));
        edit.add(item9 = new MenuItem("-"));
    }
}```
Menu sub = new Menu("Special");
MenuItem item10, item11, item12;
sub.add(item10 = new MenuItem("First"));
sub.add(item11 = new MenuItem("Second"));
sub.add(item12 = new MenuItem("Third"));
edit.add(sub);

// These are checkable menu items.
debug = new CheckboxMenuItem("Debug");
edit.add(debug);
test = new CheckboxMenuItem("Testing");
edit.add(test);

mbar.add(edit);

// Create an object to handle action and item events.
MyMenuHandler handler = new MyMenuHandler();

// Register to receive those events.
item1.addActionListener(handler);
item2.addActionListener(handler);
item3.addActionListener(handler);
item4.addActionListener(handler);
item6.addActionListener(handler);
item7.addActionListener(handler);
item8.addActionListener(handler);
item9.addActionListener(handler);
item10.addActionListener(handler);
item11.addActionListener(handler);
item12.addActionListener(handler);
debug.addItemListener(handler);
test.addItemListener(handler);

// Use a lambda expression to handle the Quit selection.
item5.addActionListener((ae) -> System.exit(0));

addWindowListener(new WindowAdapter() {
    public void windowClosing(WindowEvent we) {
        System.exit(0);
    }
});

public void paint(Graphics g) {
    g.drawString(msg, 10, 220);
if(debug.getState())
    g.drawString("Debug is on.", 10, 240);
else
    g.drawString("Debug is off.", 10, 240);

if(test.getState())
    g.drawString("Testing is on.", 10, 260);
else
    g.drawString("Testing is off.", 10, 260);

public static void main(String[] args) {
    MenuDemo appwin = new MenuDemo();

    appwin.setSize(new Dimension(250, 300));
    appwin.setTitle("MenuDemo");
    appwin.setVisible(true);
}

// An inner class for handling action and item events
// for the menu.
class MyMenuHandler implements ActionListener, ItemListener {

    // Handle action events.
    public void actionPerformed(ActionEvent ae) {
        msg = "You selected ";
        String arg = ae.getActionCommand();
if(arg.equals("New..."))
    msg += "New."
else if(arg.equals("Open..."))
    msg += "Open."
else if(arg.equals("Close"))
    msg += "Close."
else if(arg.equals("Edit"))
    msg += "Edit."
else if(arg.equals("Cut"))
    msg += "Cut."
else if(arg.equals("Copy"))
    msg += "Copy."
else if(arg.equals("Paste"))
    msg += "Paste."
else if(arg.equals("First"))
    msg += "First."
else if(arg.equals("Second"))
    msg += "Second."
else if(arg.equals("Third"))
    msg += "Third."
else if(arg.equals("Debug"))
    msg += "Debug."
else if(arg.equals("Testing"))
    msg += "Testing."

    repaint();

    // Handle item events.
    public void itemStateChanged(ItemEvent ie) {
        repaint();
    }
}
There is one other menu-related class that you might find interesting: **PopupMenu**. It works just like **Menu**, but produces a menu that can be displayed at a specific location. **PopupMenu** provides a flexible, useful alternative for some types of menuing situations.

## Dialog Boxes

Often, you will want to use a *dialog box* to hold a set of related controls. Dialog boxes are primarily used to obtain user input and are often child windows of a top-level window. Dialog boxes don’t have menu bars, but in other respects, they function like frame windows. (You can add controls to them, for example, in the same way that you add controls to a frame window.) Dialog boxes may be modal or modeless. In general terms, when a *modal* dialog box is active, you cannot access other windows in your program (except for child windows of the dialog window) until you have closed the dialog box. When a *modeless* dialog box is active, input focus can be directed to another window in your program. Thus, other parts of your program remain active and accessible. Beginning with JDK 6, modal dialog boxes can be created with three different types of modality, as specified by the **Dialog.ModalityType** enumeration. The default is **APPLICATION_MODAL**, which prevents the use of other top-level windows in the application. This is the traditional type of modality. Other types are **DOCUMENT_MODAL** and **TOOLKIT_MODAL**. The **MODELESS** type is also included.

In the AWT, dialog boxes are of type **Dialog**. Two commonly used constructors
are shown here:

Dialog(Frame parentWindow, boolean mode)
Dialog(Frame parentWindow, String title, boolean mode)

Here, parentWindow is the owner of the dialog box. If mode is true, the dialog box uses the default modality. Otherwise, it is modeless. The title of the dialog box can be passed in title. Generally, you will subclass Dialog, adding the functionality required by your application.

Following is a modified version of the preceding menu program that displays a modeless dialog box when the New option is chosen. Notice that when the dialog box is closed, dispose() is called. This method is defined by Window, and it frees all system resources associated with the dialog box window.

// Illustrate a dialog box.
import java.awt.*;
import java.awt.event.*;

class DialogDemo extends Frame {
    String msg = "";
    CheckboxMenuItem debug, test;
    SampleDialog myDialog;

    public DialogDemo() {

        // Create the dialog box.
        myDialog = new SampleDialog(this, "New Dialog Box");
// Create menu bar and add it to frame.
MenuBar mbar = new MenuBar();
setMenuBar(mbar);

// Create the menu items.
Menu file = new Menu("File");
MenuItem item1, item2, item3, item4, item5;
file.add(item1 = new MenuItem("New..."));
file.add(item2 = new MenuItem("Open..."));
file.add(item3 = new MenuItem("Close");
file.add(item4 = new MenuItem("-");
file.add(item5 = new MenuItem("Quit..."));
mbar.add(file);

Menu edit = new Menu("Edit");
MenuItem item6, item7, item8, item9;
edit.add(item6 = new MenuItem("Cut");
edit.add(item7 = new MenuItem("Copy");
edit.add(item8 = new MenuItem("Paste");
edit.add(item9 = new MenuItem("-"));

Menu sub = new Menu("Special");
MenuItem item10, item11, item12;
sub.add(item10 = new MenuItem("First");
sub.add(item11 = new MenuItem("Second");
sub.add(item12 = new MenuItem("Third");
edit.add(sub);
// These are checkable menu items.
d debug = new CheckboxMenuItem("Debug");
edit.add(debug);
test = new CheckboxMenuItem("Testing");
edit.add(test);

mbar.add(edit);

// Create an object to handle action and item events.
MyMenuHandler handler = new MyMenuHandler();

// Register to receive those events.
item1.addActionListener(handler);
item2.addActionListener(handler);
item3.addActionListener(handler);
item4.addActionListener(handler);
item6.addActionListener(handler);
item7.addActionListener(handler);
item8.addActionListener(handler);
item9.addActionListener(handler);
item10.addActionListener(handler);
item11.addActionListener(handler);
item12.addActionListener(handler);
d debug.addItemListener(handler);
test.addItemListener(handler);
// Use a lambda expression to handle the Quit selection.
item5.addActionListener((ae) -> System.exit(0));

addWindowListener(new WindowAdapter() {
    public void windowClosing(WindowEvent we) {
        System.exit(0);
    }
});

public void paint(Graphics g) {
    g.drawString(msg, 10, 220);

    if(debug.getState())
        g.drawString("Debug is on.", 10, 240);
    else
        g.drawString("Debug is off.", 10, 240);

    if(test.getState())
        g.drawString("Testing is on.", 10, 260);
    else
        g.drawString("Testing is off.", 10, 260);
}

public static void main(String[] args) {
    DialogDemo appwin = new DialogDemo();
appwin.setSize(new Dimension(250, 300));
appwin.setTitle("DialogDemo");
appwin.setVisible(true);

// An inner class for handling action and item events
// for the menu.
class MyMenuHandler implements ActionListener, ItemListener {

    // Handle action events.
    public void actionPerformed(ActionEvent ae) {
        msg = "You selected ";
        String arg = ae.getActionCommand();

        if(arg.equals("New...")) {
            msg += "New. ";
            myDialog.setVisible(true);
        } else if(arg.equals("Open..."))
            msg += "Open. ";
        else if(arg.equals("Close"))
            msg += "Close. ";
        else if(arg.equals("Edit"))
            msg += "Edit. ";
else if(arg.equals("Cut"))
    msg += "Cut.");
else if(arg.equals("Copy"))
    msg += "Copy.");
else if(arg.equals("Paste"))
    msg += "Paste.");
else if(arg.equals("First"))
    msg += "First.");
else if(arg.equals("Second"))
    msg += "Second.");
else if(arg.equals("Third"))
    msg += "Third.");
else if(arg.equals("Debug"))
    msg += "Debug.");
else if(arg.equals("Testing"))
    msg += "Testing.");

repaint();

// Handle item events.
public void itemStateChanged(ItemEvent ie) {
    repaint();
}
// Create a subclass of Dialog.
class SampleDialog extends Dialog {
    SampleDialog(Frame parent, String title) {
        super(parent, title, false);
        setLayout(new FlowLayout());
        setSize(300, 200);

        add(new Label("Press this button:"));

        Button b;
        add(b = new Button("Cancel"));
        b.addActionListener((ae) -> dispose());

        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                dispose();
            }
        });
    }

    public void paint(Graphics g) {
        g.drawString("This is in the dialog box", 20, 80);
    }
}

Here is sample output from the DialogDemo program:

TIP On your own, try defining dialog boxes for the other options presented by the menus.

A Word About Overriding paint()
Before concluding our examination of AWT controls, a short word about overriding `paint()` is in order. Although not relevant to the simple AWT examples shown in this book, when overriding `paint()`, there are times when it is necessary to call the superclass implementation of `paint()`. Therefore, for some programs, you will need to use this `paint()` skeleton:

```java
public void paint(Graphics g) {
    // code to repaint this window

    // Call superclass paint()
    super.paint(g);
}
```

In Java, there are two general types of components: heavyweight and lightweight. A heavyweight component has its own native window, which is called its `peer`. A lightweight component is implemented completely in Java code and uses the window provided by an ancestor. The AWT controls described and used in this chapter are all heavyweight. However, if a container holds any lightweight components (that is, has lightweight child components), your override of `paint()` for that container must call `super.paint()`. By calling `super.paint()`, you ensure that any lightweight child components, such as lightweight controls, get properly painted. If you are unsure of a child component’s type, you can call `isLightweight()`, defined by `Component`, to find out. It returns `true` if the component is lightweight, and `false` otherwise.
CHAPTER
27 Images

This chapter examines the Image class and the java.awt.image package. Together, they provide support for imaging (the display and manipulation of graphical images). An image is simply a rectangular graphical object. Images are a key component of web design. In fact, the inclusion of the \texttt{<img>} tag in the Mosaic browser at NCSA (National Center for Supercomputer Applications) was a catalyst that helped the Web begin to grow explosively in 1993. This tag was used to include an image inline with the flow of hypertext. Java expands upon this basic concept, allowing images to be managed under program control. Because of its importance, Java provides extensive support for imaging.

Images are supported by the Image class, which is part of the java.awt package. Images are manipulated using the classes found in the java.awt.image package. There are a large number of imaging classes and interfaces defined by java.awt.image, and it is not possible to examine them all. Instead, we will focus on those that form the foundation of imaging. Here are the java.awt.image classes discussed in this chapter:

<table>
<thead>
<tr>
<th>CropImageFilter</th>
<th>MemoryImageSource</th>
</tr>
</thead>
<tbody>
<tr>
<td>FilteredImageSource</td>
<td>PixelGrabber</td>
</tr>
<tr>
<td>ImageFilter</td>
<td>RGBImageFilter</td>
</tr>
</tbody>
</table>

The interfaces that we will use are ImageConsumer and ImageProducer.

File Formats

Originally, web images could only be in GIF format. The GIF image format was created by CompuServe in 1987 to make it possible for images to be viewed while online, so it was well suited to the Internet. GIF images can have only up to 256 colors each. This limitation caused the major browser vendors to add support for JPEG images in 1995. The JPEG format was created by a group of photographic experts to store full-color-spectrum, continuous-tone images. These images, when properly created, can be of much higher fidelity as well as more highly compressed than a GIF encoding of the same source image. Another file format is PNG. It too is an alternative to GIF. In almost all cases, you will never care or notice which format
is being used in your programs. The Java image classes abstract the differences behind a clean interface.

**Image Fundamentals: Creating, Loading, and Displaying**

There are three common operations that occur when you work with images: creating an image, loading an image, and displaying an image. In Java, the `Image` class is used to refer to images in memory and to images that must be loaded from external sources. Thus, Java provides ways for you to create a new image object and ways to load one. It also provides a means by which an image can be displayed. Let’s look at each.

**Creating an Image Object**

You might expect that you create a memory image using something like the following:

```java
Image test = new Image(200, 100); // Error -- won’t work
```

Not so. Because images must eventually be painted on a window to be seen, the `Image` class doesn’t have enough information about its environment to create the proper data format for the screen. Therefore, the `Component` class in `java.awt` has a factory method called `createImage()` that is used to create `Image` objects. (Remember that all of the AWT components are subclasses of `Component`, so all support this method.)

The `createImage()` method has the following two forms:

```java
Image createImage(ImageProducer imgProd)
Image createImage(int width, int height)
```

The first form returns an image produced by `imgProd`, which is an object of a class that implements the `ImageProducer` interface. (We will look at image producers later.) The second form returns a blank (that is, empty) image that has the specified width and height. Here is an example:

```java
Canvas c = new Canvas();
Image test = c.createImage(200, 100);
```

This creates an instance of `Canvas` and then calls the `createImage()` method to
actually make an **Image** object. At this point, the image is blank. Later, you will see how to write data to it.

**Loading an Image**

Another way to obtain an image is to load one, either from a file on the local file system or from a URL. Here, we will use the local file system. The easiest way to load an image is to use one of the static methods defined by the **ImageIO** class. **ImageIO** provides extensive support for reading and writing images. It is packaged in **javax.imageio**, and beginning with JDK 9, **javax.imageio** is part of the **java.desktop** module. The method that loads an image is called **read()**. The form we will use is shown here:

```
static BufferedImage read(File imageFile) throws IOException
```

Here, **imageFile** specifies the file that contains the image. It returns a reference to the image in the form of a **BufferedImage**, which is a subclass of **Image** that includes a buffer. Null is returned if the file does not contain a valid image.

**Displaying an Image**

Once you have an image, you can display it by using **drawImage()**, which is a member of the **Graphics** class. It has several forms. The one we will be using is shown here:

```
boolean drawImage(Image imgObj, int left, int top, ImageObserver imgOb)
```

This displays the image passed in **imgObj** with its upper-left corner specified by **left** and **top**. **imgOb** is a reference to a class that implements the **ImageObserver** interface. This interface is implemented by all AWT (and Swing) components. An image observer is an object that can monitor an image while it loads. When no image observer is needed, **imgOb** can be **null**.

Using **read()** and **drawImage()**, it is actually quite easy to load and display an image. Here is a program that loads and displays a single image. The file **Lilies.jpg** is loaded, but you can substitute any image you like (just make sure it is available in the same directory as the program). Sample output is shown in **Figure 27-1**.
// Load and display an image.
import java.awt.*;
import java.awt.event.*;
import javax.imageio.*;
import java.io.*;

public class SimpleImageLoad extends Frame {
    Image img;

    public SimpleImageLoad() {
        try {
            File imageFile = new File("Lilies.jpg");

            // Load the image.
            img = ImageIO.read(imageFile);
        } catch (IOException exc) {
            System.out.println("Cannot load image file.");
            System.exit(0);
        }

        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }

    public void paint(Graphics g) {
        g.drawImage(img, getInsets().left, getInsets().top, null);
    }

    public static void main(String[] args) {
        SimpleImageLoad appwin = new SimpleImageLoad();

        appwin.setSize(new Dimension(400, 365));
        appwin.setTitle("SimpleImageLoad");
        appwin.setVisible(true);
    }
}
Double Buffering

Not only are images useful for storing pictures, as we’ve just shown, but you can also use them as offscreen drawing surfaces. This allows you to render any image, including text and graphics, to an offscreen buffer that you can display at a later time. The advantage to doing this is that the image is seen only when it is complete. Drawing a complicated image could take several milliseconds or more, which can be seen by the user as flashing or flickering. This flashing is distracting and causes the user to perceive your rendering as slower than it actually is. Use of an offscreen image to reduce flicker is called double buffering, because the screen is considered a buffer for pixels, and the offscreen image is the second buffer, where you can prepare pixels for display.

Earlier in this chapter, you saw how to create a blank Image object. Now you will see how to draw on that image rather than the screen. As you recall from earlier chapters, you need a Graphics object in order to use any of Java’s rendering methods. Conveniently, the Graphics object that you can use to draw on an Image is available via the getGraphics() method. Here is a code fragment that creates a new image, obtains its graphics context, and fills the entire image with red pixels:
Canvas c = new Canvas();
Image test = c.createImage(200, 100);
Graphics gc = test.getGraphics();
gc.setColor(Color.red);
gc.fillRect(0, 0, 200, 100);

Once you have constructed and filled an offscreen image, it will still not be visible. To actually display the image, call `drawImage()`. Here is an example that draws a time-consuming image to demonstrate the difference that double buffering can make in perceived drawing time:
// Demonstrate the use of an off-screen buffer.
import java.awt.*;
import java.awt.event.*;

public class DoubleBuffer extends Frame {
    int gap = 3;
    int mx, my;
    boolean flicker = true;
    Image buffer = null;
    int w = 400, h = 400;

    public DoubleBuffer() {
        addMouseMotionListener(new MouseMotionAdapter() {
            public void mouseDragged(MouseEvent me) {
                mx = me.getX();
                my = me.getY();
                flicker = false;
                repaint();
            }
            public void mouseMoved(MouseEvent me) {
                mx = me.getX();
                my = me.getY();
                flicker = true;
                repaint();
            }
        });

        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }

    public void paint(Graphics g) {
        Graphics screenGC = null;

        if (!flicker) {
            screenGC = g;
            g = buffer.getGraphics();
        }
    }
}
This simple program has a complicated paint( ) method. It fills the background with blue and then draws a red moiré pattern on top of that. It paints some black text on top of that and then paints a yellow circle centered at the coordinates mx, my. The mouseMoved( ) and mouseDragged( ) methods are overridden to track the mouse position. These methods are identical, except for the setting of the flicker Boolean variable. mouseMoved( ) sets flicker to true, and mouseDragged( ) sets it to false. This has the effect of calling repaint( ) with flicker set to true when the mouse is moved (but no button is pressed) and set to false when the mouse is dragged with

```java
g.setColor(Color.blue);
g.fillRect(0, 0, w, h);
g.setColor(Color.red);
    for (int i=0; i<w; i+=gap)
        g.drawLine(i, 0, w-i, h);
    for (int i=0; i<h; i+=gap)
        g.drawLine(0, i, w, h-i);

g.setColor(Color.black);
g.drawString("Press mouse button to double buffer", 10, h/2);

g.setColor(Color.yellow);
g.fillOval(mx - gap, my - gap, gap*2+1, gap*2+1);

if (!flicker) {
    screen.gc.drawImage(buffer, 0, 0, null);
}
}

public void update(Graphics g) {
    paint(g);
}

public static void main(String[] args) {
    DoubleBuffer appwin = new DoubleBuffer();

    appwin.setSize(new Dimension(400, 400));
    appwin.setTitle("DoubleBuffer");
    appwin.setVisible(true);

    // Create an off-screen buffer.
    appwin.buffer = appwin.createImage(appwin.w, appwin.h);
}
```
any button pressed.

When `paint()` gets called with `flicker` set to `true`, we see each drawing operation as it is executed on the screen. In the case where a mouse button is pressed and `paint()` is called with `flicker` set to `false`, we see quite a different picture. The `paint()` method swaps the `Graphics` reference `g` with the graphics context that refers to the offscreen canvas, `buffer`, which we created in `main()`. Then all of the drawing operations are invisible. At the end of `paint()`, we simply call `drawImage()` to show the results of these drawing methods all at once.

Sample output is shown in **Figure 27-2**. The left snapshot is what the screen looks like with the mouse button not pressed. As you can see, the image was in the middle of repainting when this snapshot was taken. The right snapshot shows how, when a mouse button is pressed, the image is always complete and clean due to double buffering.

![Figure 27-2](image)

**Figure 27-2** Output from **DoubleBuffer** without (left) and with (right) double buffering

### ImageProducer

`ImageProducer` is an interface for objects that want to produce data for images. An object that implements the `ImageProducer` interface will supply integer or byte arrays that represent image data and produce `Image` objects. As you saw earlier, one form of the `createImage()` method takes an `ImageProducer` object as its argument. There are two image producers contained in `java.awt.image: MemoryImageSource` and `FilteredImageSource`. Here, we will examine `MemoryImageSource` and create a new `Image` object from generated data.
MemoryImageSource

MemoryImageSource is a class that creates a new Image from an array of data. It defines several constructors. Here is the one we will be using:

    MemoryImageSource(int width, int height, int pixel[], int offset, int scanLineWidth)

The MemoryImageSource object is constructed out of the array of integers specified by pixel, in the default RGB color model to produce data for an Image object. In the default color model, a pixel is an integer with Alpha, Red, Green, and Blue (0xAARRGGBB). The Alpha value represents a degree of transparency for the pixel. Fully transparent is 0 and fully opaque is 255. The width and height of the resulting image are passed in width and height. The starting point in the pixel array to begin reading data is passed in offset. The width of a scan line (which is often the same as the width of the image) is passed in scanLineWidth.

The following short example generates a MemoryImageSource object using a variation on a simple algorithm (a bitwise-exclusive-OR of the x and y address of each pixel) from the book Beyond Photography: The Digital Darkroom by Gerard J. Holzmann (Prentice Hall, 1988).
// Create an image in memory.
import java.awt.*;
import java.awt.image.*;
import java.awt.event.*;

public class MemoryImageGenerator extends Frame {
    Image img;
    int w = 512;
    int h = 512;

    public MemoryImageGenerator() {
        int pixels[] = new int[w * h];
        int i = 0;

        for(int y=0; y<h; y++) {
            for(int x=0; x<w; x++) {
                int r = (x*y)&0xff;
                int g = (x*2^y*2)&0xff;
                int b = (x*4^y*4)&0xff;
                pixels[i++] = (255 << 24) | (r << 16) | (g << 8) | b;
            }
        }
        img = createImage(new MemoryImageSource(w, h, pixels, 0, w));

        addWindowListener(new WindowAdapter() {
            public void windowClosing(WindowEvent we) {
                System.exit(0);
            }
        });
    }

    public void paint(Graphics g) {
        g.drawImage(img, getInsets().left, getInsets().top, null);
    }

    public static void main(String[] args) {
        MemoryImageGenerator appwin = new MemoryImageGenerator();

        appwin.setSize(new Dimension(400, 400));
        appwin.setTitle("MemoryImageGenerator");
        appwin.setVisible(true);
    }
}
The data for the new `MemoryImageSource` is created in the constructor. An array of integers is created to hold the pixel values; the data is generated in the nested `for` loops where the `r`, `g`, and `b` values get shifted into a pixel in the `pixels` array. Finally, `createImage()` is called with a new instance of a `MemoryImageSource` created from the raw pixel data as its parameter. Figure 27-3 shows the image.

![Sample output from MemoryImageGenerator](image.png)

**Figure 27-3**  Sample output from `MemoryImageGenerator`

### ImageConsumer

`ImageConsumer` is an interface for objects that want to take pixel data from images and supply it as another kind of data. This, obviously, is the opposite of `ImageProducer`, described earlier. An object that implements the `ImageConsumer` interface is going to create `int` or `byte` arrays that represent pixels from an `Image` object. We will examine the `PixelGrabber` class, which is a simple implementation of the `ImageConsumer` interface.

### PixelGrabber

The `PixelGrabber` class is defined within `java.lang.image`. It is the inverse of the `MemoryImageSource` class. Rather than constructing an image from an array of pixel values, it takes an existing image and *grabs* the pixel array from it. To use
**PixelGrabber**, you first create an array of **ints** big enough to hold the pixel data, and then you create a **PixelGrabber** instance passing in the rectangle that you want to grab. Finally, you call **grabPixels( )** on that instance.

The **PixelGrabber** constructor that is used in this chapter is shown here:

```
PixelGrabber(Image imgObj, int left, int top, int width, int height, int pixel [ ],
              int offset, int scanLineWidth)
```

Here, **imgObj** is the object whose pixels are being grabbed. The values of **left** and **top** specify the upper-left corner of the rectangle, and **width** and **height** specify the dimensions of the rectangle from which the pixels will be obtained. The pixels will be stored in **pixel** beginning at **offset**. The width of a scan line (which is often the same as the width of the image) is passed in **scanLineWidth**.

**grabPixels( )** is defined like this:

```
boolean grabPixels( )
    throws InterruptedException

boolean grabPixels(long milliseconds)
    throws InterruptedException
```

Both methods return **true** if successful and **false** otherwise. In the second form, **milliseconds** specifies how long the method will wait for the pixels. Both throw **InterruptedException** if execution is interrupted by another thread.

Here is an example that grabs the pixels from an image and then creates a histogram of pixel brightness. The **histogram** is simply a count of pixels that are a certain brightness for all brightness settings between 0 and 255. After the program paints the image, it draws the histogram over the top.
// Demonstrate PixelGrabber.
import java.awt.*;
import java.awt.event.*;
import java.awt.image.*;
import javax.imageio.*;
import java.io.*;

public class HistoGrab extends Frame {
    Dimension d;
    Image img;
    int iw, ih;
    int pixels[];
    int hist[] = new int[256];
    int max_hist = 0;
    Insets ins;

    public HistoGrab() {
        try {
            File imageFile = new File("Lilies.jpg");

            // Load the image.
            img = ImageIO.read(imageFile);

            iw = img.getWidth(null);
            ih = img.getHeight(null);
            pixels = new int[iw * ih];
            PixelGrabber pg = new PixelGrabber(img, 0, 0, iw, ih,
                                                pixels, 0, iw);

            pg.grabPixels();
        } catch (InterruptedException e) {
            System.out.println("Interrupted");
            return;
        } catch (IOException exc) {
            System.out.println("Cannot load image file.");
            System.exit(0);
        }
    }
}
for (int i=0; i<iw*ih; i++) {
    int p = pixels[i];
    int r = 0xff & (p >> 16);
    int g = 0xff & (p >> 8);
    int b = 0xff & (p);
    int y = (int) (.33 * r + .56 * g + .11 * b);
    hist[y]++;
}
for (int i=0; i<256; i++) {
    if (hist[i] > max_hist)
        max_hist = hist[i];
}

addWindowListener(new WindowAdapter() {
    public void windowClosing(WindowEvent we) {
        System.exit(0);
    }
});

public void paint(Graphics g) {
    // Get the border/header insets.
    ins = getInsets();

    g.drawImage(img, ins.left, ins.top, null);

    int x = (iw - 256) / 2;
    int lasty = ih - ih * hist[0] / max_hist;

    for (int i=0; i<256; i++, x++) {
        int y = ih - ih * hist[i] / max_hist;
        g.setColor(new Color(i, i, i));
        g.fillRect(x+ins.left, y+ins.top, 1, ih-y);
        g.setColor(Color.red);
        g.drawLine((x-1)+ins.left, lasty+ins.top, x+ins.left, y+ins.top);
        lasty = y;
    }
}

public static void main(String[] args) {
    HistoGrab appwin = new HistoGrab();

    appwin.setSize(new Dimension(400, 380));
    appwin.setTitle("HistoGrab");
    appwin.setVisible(true);
}
Figure 27-4 shows an example image and its histogram.

![Image output from HistoGrab](image)

**ImageFilter**

Given the *ImageProducer* and *ImageConsumer* interface pair—and their concrete classes *MemoryImageSource* and *PixelGrabber*—you can create an arbitrary set of translation filters that takes a source of pixels, modifies them, and passes them on to an arbitrary consumer. This mechanism is analogous to the way concrete classes are created from the abstract I/O classes *InputStream*, *OutputStream*, *Reader*, and *Writer* (described in Chapter 21). This stream model for images is completed by the introduction of the *ImageFilter* class. Some subclasses of *ImageFilter* in the *java.awt.image* package are *AreaAveragingScaleFilter*, *CropImageFilter*, *ReplicateScaleFilter*, and *RGBImageFilter*. There is also an implementation of *ImageProducer* called *FilteredImageSource*, which takes an arbitrary *ImageFilter* and wraps it around an *ImageProducer* to filter the pixels it produces. An instance of *FilteredImageSource* can be used as an *ImageProducer* in calls to *createImage()* in much the same way that *BufferedInputStreams* can be used as *InputStreams*. 
In this chapter, we examine two filters: **CropImageFilter** and **RGBImageFilter**.

**CropImageFilter**

**CropImageFilter** filters an image source to extract a rectangular region. One situation in which this filter is valuable is where you want to use several small images from a single, larger source image. Loading twenty 2K images takes much longer than loading a single 40K image that has many frames of an animation tiled into it. If every subimage is the same size, then you can easily extract these images by using **CropImageFilter** to disassemble the block once your program starts. Here is an example that creates 16 images taken from a single image. The tiles are then scrambled by swapping a random pair from the 16 images 32 times.
// Demonstrate CropImageFilter.
import java.awt.*;
import java.awt.image.*;
import java.awt.event.*;
import javax.imageio.*;
import java.io.*;

public class TileImage extends Frame {
    Image img;
    Image cell[] = new Image[4*4];
    int iw, ih;
    int tw, th;

    public TileImage() {
        try {
            File imageFile = new File("Lilies.jpg");

            // Load the image.
            img = ImageIO.read(imageFile);

            iw = img.getWidth(null);
            ih = img.getHeight(null);
            tw = iw / 4;
            th = ih / 4;

            CropImageFilter f;
            FilteredImageSource fis;

            for (int y=0; y<4; y++) {
                for (int x=0; x<4; x++) {
                    f = new CropImageFilter(tw*x, th*y, tw, th);
                    fis = new FilteredImageSource(img.getSource(), f);
                    int i = y*4+x;
                    cell[i] = createImage(fis);
                }
            }
        }
    }
}
for (int i=0; i<32; i++) {
    int si = (int)(Math.random() * 16);
    int di = (int)(Math.random() * 16);
    Image tmp = cell[si];
    cell[si] = cell[di];
    cell[di] = tmp;
} catch (IOException exc) {
    System.out.println("Cannot load image file.");
    System.exit(0);
}

addWindowListener(new WindowAdapter() {
    public void windowClosing(WindowEvent we) {
        System.exit(0);
    }
});

public void paint(Graphics g) {
    for (int y=0; y<4; y++) {
        for (int x=0; x<4; x++) {
            g.drawImage(cell[y*4+x], x * tw + getInsets().left,
                         y * th + getInsets().top, null);
        }
    }
}

public static void main(String[] args) {
    TileImage appwin = new TileImage();

    appwin.setSize(new Dimension(420, 420));
    appwin.setTitle("TileImage");
    appwin.setVisible(true);
}

Figure 27-5 shows the flowers image scrambled by TileImage.
The `RGBImageFilter` is used to convert one image to another, pixel by pixel, transforming the colors along the way. This filter could be used to brighten an image, to increase its contrast, or even to convert it to grayscale. To demonstrate `RGBImageFilter`, we have developed a somewhat complicated example that employs a dynamic plug-in strategy for image-processing filters. We’ve created an interface for generalized image filtering so that a program can simply load these filters at run time without having to know about all of the `ImageFilters` in advance. This example consists of the main class called `ImageFilterDemo`, the interface called `PlugInFilter`, and a utility class called `LoadedImage`. Also included are three filters—`Grayscale`, `Invert`, and `Contrast`—which simply manipulate the color space of the source image using `RGBImageFilters`, and two more classes—`Blur` and `Sharpen`—which do more complicated "convolution" filters that change pixel data based on the pixels surrounding each pixel of source data. `Blur` and `Sharpen` are subclasses of an abstract helper class called `Convolver`. Let’s look at each part of our example.

`ImageFilterDemo.java`
The `ImageFilterDemo` class is the main class for the sample image filters. It employs the default `BorderLayout`, with a `Panel` at the `South` position to hold the buttons that will represent each filter. A `Label` object occupies the `North` slot for informational messages about filter progress. The `Center` is where the image (which is encapsulated in the `LoadedImage Canvas` subclass, described later) is put.

The `actionPerformed()` method is interesting because it uses the label from a button as the name of a filter class that it loads. This method is robust and takes appropriate action if the button does not correspond to a proper class that implements `PlugInFilter`. 
// Demonstrate image filters.
import java.awt.*;
import java.awt.event.*;
import javax.imageio.*;
import java.io.*;
import java.lang.reflect.*;

public class ImageFilterDemo extends Frame implements ActionListener {
    Image img;
    PlugInFilter pif;
    Image fimg;
    Image curImg;
    LoadedImage lim;
    Label lab;
    Button reset;

    // Names of the filters.
    String[] filters = { "Grayscale", "Invert", "Contrast", "Blur", "Sharpen" };

    public ImageFilterDemo() {
        Panel p = new Panel();
        add(p, BorderLayout.SOUTH);

        // Create Reset button.
        reset = new Button("Reset");
        reset.addActionListener(this);
        p.add(reset);

        // Add the filter buttons.
        for(String fstr: filters) {
            Button b = new Button(fstr);
            b.addActionListener(this);
            p.add(b);
        }
    }
// Create the top label.
lab = new Label("");  
add(lab, BorderLayout.NORTH);

// Load the image.
try {
    File imageFile = new File("Lilies.jpg");

    // Load the image.
    img = ImageIO.read(imageFile);
} catch (IOException exc) {
    System.out.println("Cannot load image file.");
    System.exit(0);
}

// Get a LoadedImage and add it to the center.
lim = new LoadedImage(img);
add(lim, BorderLayout.CENTER);

addWindowListener(new WindowAdapter() {
    public void windowClosing(WindowEvent we) {
        System.exit(0);
    }
});
public void actionPerformed(ActionEvent ae) {
    String a = "";

    try {
        a = ae.getActionCommand();
        if (a.equals("Reset")) {
            lim.set(img);
            lab.setText("Normal");
        } else {
            // Get the selected filter.
            pif = (PlugInFilter)
                (Class.forName(a)).getConstructor().newInstance();
            fimg = pif.filter(this, img);
            lim.set(fimg);
            lab.setText("Filtered: " + a);
        }
        repaint();
    } catch (ClassNotFoundException e) {
        lab.setText(a + " not found");
        lim.set(img);
        repaint();
    } catch (InstantiationException e) {
        lab.setText("couldn't new " + a);  
    } catch (IllegalAccessException e) {  
        lab.setText("no access: " + a);     
    } catch (NoSuchMethodException | InvocationTargetException e) { 
        lab.setText("Filter creation error: " + e);
    }
}

public static void main(String[] args) {
    ImageFilterDemo appwin = new ImageFilterDemo();

    appwin.setSize(new Dimension(420, 420));
    appwin.setTitle("ImageFilterDemo");
    appwin.setVisible(true);
}

Figure 27-6 shows what the program looks like when it is first loaded.
PlugInFilter.java

PlugInFilter is a simple interface used to abstract image filtering. It has only one method, filter( ), which takes the frame and the source image and returns a new image that has been filtered in some way.

```java
interface PlugInFilter {
    java.awt.Image filter(java.awt.Frame f, java.awt.Image in);
}
```

LoadedImage.java

LoadedImage is a convenient subclass of Canvas. It behaves properly under layout manager control, because it overrides the getPreferredSize() and getMinimumSize() methods. Also, it has a method called set( ) that can be used to set a new Image to be displayed in this Canvas. That is how the filtered image is displayed after the plug-in is finished.
The `Grayscale` filter is a subclass of `RGBImageFilter`, which means that `Grayscale` can use itself as the `ImageFilter` parameter to `FilteredImageSource`’s constructor. Then all it needs to do is override `filterRGB()` to change the incoming color values. It takes the red, green, and blue values and computes the brightness of the pixel, using the NTSC (National Television Standards Committee) color-to-brightness conversion factor. It then simply returns a gray pixel that is the same brightness as the color source.
The **Invert** filter is also quite simple. It takes apart the red, green, and blue values and then inverts them by subtracting them from 255. These inverted values are packed back into a pixel value and returned.

```java
// Invert colors filter.
import java.awt.*;
import java.awt.image.*;

class Invert extends RGBImageFilter implements PlugInFilter {
    public Invert() {
    }

    public Image filter(Frame f, Image in) {
        return f.createImage(new FilteredImageSource(in.getSource(), this));
    }

    public int filterRGB(int x, int y, int rgb) {
        int r = (rgb >> 16) & 0xff;
        int g = (rgb >> 8) & 0xff;
        int b = rgb & 0xff;
        int k = (int) (.56 * g + .33 * r + .11 * b);
        return (0xff000000 | k << 16 | k << 8 | k);
    }
}
```
Figure 27-7 shows the image after it has been run through the **Invert** filter.

![Invert Filter Image](image)

**Figure 27-7** Using the **Invert** filter with **ImageFilterDemo**

**Contrast.java**

The **Contrast** filter is very similar to **Grayscale**, except its override of `filterRGB()` is slightly more complicated. The algorithm it uses for contrast enhancement takes the red, green, and blue values separately and boosts them by 1.2 times if they are already brighter than 128. If they are below 128, then they are divided by 1.2. The boosted values are properly clamped at 255 by the `multclamp()` method.

```java
// Contrast filter.
import java.awt.*;
import java.awt.image.*;
```
public class Contrast extends RGBImageFilter implements PlugInFilter {
    public Image filter(Frame f, Image in) {
        return f.createImage(new FilteredImageSource(in.getSource(), this));
    }

    private int multclamp(int in, double factor) {
        int = (int) (in * factor);
        return in > 255 ? 255 : in;
    }

    double gain = 1.2;
    private int cont(int in) {
        return (in < 128) ? (int)(in/gain) : multclamp(in, gain);
    }

    public int filterRGB(int x, int y, int rgb) {
        int r = cont((rgb >> 16) & 0xff);
        int g = cont((rgb >> 8) & 0xff);
        int b = cont(rgb & 0xff);
        return (0xff000000 | r << 16 | g << 8 | b);
    }
}

Figure 27-8 shows the image after Contrast is pressed.
The abstract class `Convolver` handles the basics of a convolution filter by implementing the `ImageConsumer` interface to move the source pixels into an array called `imgpixels`. It also creates a second array called `newimgpixels` for the filtered data. Convolution filters sample a small rectangle of pixels around each pixel in an image, called the *convolution kernel*. This area, $3 \times 3$ pixels in this demo, is used to decide how to change the center pixel in the area.

**NOTE** The reason that the filter can’t modify the `imgpixels` array in place is that the next pixel on a scan line would try to use the original value for the previous pixel, which would have just been filtered away.

The two concrete subclasses, shown in the next section, simply implement the `convolve()` method, using `imgpixels` for source data and `newimgpixels` to store the result.
// Convolution filter.
import java.awt.*;
import java.awt.image.*;

abstract class Convolver implements ImageConsumer, PlugInFilter {
    int width, height;
    int imgpixels[], newimgpixels[];
    boolean imageReady = false;

    abstract void convolve();  // filter goes here...

    public Image filter(Frame f, Image in) {
        imageReady = false;
    }
in.getSource().startProduction(this);
waitForImage();
newimgpixels = new int[width*height];

try {
    convolve();
} catch (Exception e) {
    System.out.println("Convolver failed: " + e);
    e.printStackTrace();
}

return f.createImage(
    new MemoryImageSource(width, height, newimgpixels, 0, width));

synchronized void waitForImage() {
    try {
        while(!imageReady)
            wait();
    } catch (Exception e) {
        System.out.println("Interrupted");
    }
}

public void setProperties(java.util.Hashtable<?,?> dummy) {}public void setColorModel(ColorModel dummy) {}public void setHints(int dummy) {}public synchronized void imageComplete(int dummy) {
    imageReady = true;
    notifyAll();
}
public void setDimensions(int x, int y) {
    width = x;
    height = y;
    imgpixels = new int[x*y];
}

public void setPixels(int x1, int y1, int w, int h,
                        ColorModel model, byte pixels[], int off, int scansize) {
    int pix, x, y, x2, y2, sx, sy;

    x2 = x1+w;
    y2 = y1+h;
    sy = off;
    for(y=y1; y<y2; y++) {
        sx = sy;
        for(x=x1; x<x2; x++) {
            pix = model.getRGB(pixels[sx++]);
            if((pix & 0xff000000) == 0)
                pix = 0x00ffffff;
NOTE A built-in convolution filter called **ConvolveOp** is provided by **java.awt.image**. You may want to explore its capabilities on your own.

**Blur.java**
The **Blur** filter is a subclass of **Convolver** and simply runs through every pixel in the source image array, **imgpixels**, and computes the average of the $3 \times 3$ box surrounding it. The corresponding output pixel in **newimgpixels** is that average value.
Figure 27-9 shows the image after Blur.
Sharpen.java

The **Sharpen** filter is also a subclass of **Convolver** and is (more or less) the inverse of **Blur**. It runs through every pixel in the source image array, `imgpixels`, and computes the average of the $3 \times 3$ box surrounding it, not counting the center. The corresponding output pixel in `newimgpixels` has the difference between the center pixel and the surrounding average added to it. This basically says that if a pixel is 30 brighter than its surroundings, make it another 30 brighter. If, however, it is 10 darker, then make it another 10 darker. This tends to accentuate edges while leaving smooth areas unchanged.
public class Sharpen extends Convolver {

    private final int clamp(int c) {
        return (c > 255 ? 255 : (c < 0 ? 0 : c));
    }

    public void convolve() {
        int r0=0, g0=0, b0=0;

        for(int y=1; y<height-1; y++) {
            for(int x=1; x<width-1; x++) {
                int rs = 0;
                int gs = 0;
                int bs = 0;

                for(int k=-1; k<=1; k++) {
                    for(int j=-1; j<=1; j++) {
                        int rgb = imgpixels[(y+k)*width+x+j];
                        int r = (rgb >> 16) & 0xff;
                        int g = (rgb >> 8) & 0xff;
                        int b = rgb & 0xff;
                        if (j == 0 && k == 0) {
                            r0 = r;
                            g0 = g;
                            b0 = b;
                        } else {
                            rs += r;
                            gs += g;
                            bs += b;
                        }
                    }
                }
                rs >>= 3;
                gs >>= 3;
                bs >>= 3;
                newimgpixels[y*width+x] = (0xff000000 |
                clamp(r0+r0-rs) << 16 |
                clamp(g0+g0-gs) << 8 |
                clamp(b0+b0-bs));
            }
        }
    }
}
Figure 27-10 shows the image after **Sharpen**.

![ImageFilterDemo](image)

**Figure 27-10** Using the **Sharpen** filter with **ImageFilterDemo**

### Additional Imaging Classes

In addition to the imaging classes described in this chapter, `java.awt.image` supplies several others that offer enhanced control over the imaging process and that support advanced imaging techniques. Also available is the imaging package called `javax.imageio`. It supports reading and writing images, and has plug-ins that handle various image formats. If sophisticated graphical output is of special interest to you, then you will want to explore the additional classes found in `java.awt.image` and `javax.imageio`. 
CHAPTER
From the start, Java has provided built-in support for multithreading and synchronization. For example, new threads can be created by implementing Runnable or by extending Thread; synchronization is available by use of the synchronized keyword; and interthread communication is supported by the wait( ) and notify( ) methods that are defined by Object. In general, this built-in support for multithreading was one of Java’s most important innovations and is still one of its major strengths.

However, as conceptually pure as Java’s original support for multithreading is, it is not ideal for all applications—especially those that make intensive use of multiple threads. For example, the original multithreading support does not provide several high-level features, such as semaphores, thread pools, and execution managers, that facilitate the creation of intensively concurrent programs.

It is important to explain at the outset that many Java programs make use of multithreading and are, therefore, “concurrent.” However, as it is used in this chapter, the term concurrent program refers to a program that makes extensive, integral use of concurrently executing threads. An example of such a program is one that uses separate threads to simultaneously compute the partial results of a larger computation. Another example is a program that coordinates the activities of several threads, each of which seeks access to information in a database. In this case, read-only accesses might be handled differently from those that require read/write capabilities.

To begin to handle the needs of a concurrent program, JDK 5 added the concurrency utilities, also commonly referred to as the concurrent API. The original set of concurrency utilities supplied many features that had long been wanted by programmers who develop concurrent applications. For example, it offered synchronizers (such as the semaphore), thread pools, execution managers, locks, several concurrent collections, and a streamlined way to use threads to obtain computational results.

Although the original concurrent API was impressive in its own right, it was significantly expanded by JDK 7. The most important addition was the Fork/Join Framework. The Fork/Join Framework facilitates the creation of programs that make use of multiple processors (such as those found in multicore systems). Thus, it streamlines the development of programs in which two or more pieces execute with
true simultaneity (that is, true parallel execution), not just time-slicing. As you can easily imagine, parallel execution can dramatically increase the speed of certain operations. Because multicore systems are now commonplace, the inclusion of the Fork/Join Framework was as timely as it was powerful. With the release of JDK 8, the Fork/Join Framework was further enhanced.

Furthermore, both JDK 8 and JDK 9 have added features related to other parts of the concurrent API. Thus, the concurrent API continues to evolve and expand to meet the needs of the contemporary computing environment.

The original concurrent API was quite large, and the additions made over the years have increased its size substantially. As you might expect, many of the issues surrounding the concurrency utilities are quite complex. It is beyond the scope of this book to discuss all of its facets. The preceding notwithstanding, it is important for all programmers to have a general, working knowledge of key aspects of the concurrent API. Even in programs that are not intensively parallel, features such as synchronizers, callable threads, and executors, are applicable to a wide variety of situations. Perhaps most importantly, because of the rise of multicore computers, solutions involving the Fork/Join Framework are becoming more common. For these reasons, this chapter presents an overview of several core features defined by the concurrency utilities and shows a number of examples that demonstrate their use. It concludes with an introduction to the Fork/Join Framework.

The Concurrent API Packages

The concurrency utilities are contained in the `java.util.concurrent` package and in its two subpackages: `java.util.concurrent.atomic` and `java.util.concurrent.locks`. Beginning with JDK 9, all are in the `java.base` module. A brief overview of their contents is given here.

`java.util.concurrent`

`java.util.concurrent` defines the core features that support alternatives to the built-in approaches to synchronization and interthread communication. These include

- Synchronizers
- Executors
- Concurrent collections
- The Fork/Join Framework

*Synchronizers* offer high-level ways of synchronizing the interactions between multiple threads. The synchronizer classes defined by `java.util.concurrent` are
Notice that each synchronizer provides a solution to a specific type of synchronization problem. This enables each synchronizer to be optimized for its intended use. In the past, these types of synchronization objects had to be crafted by hand. The concurrent API standardizes them and makes them available to all Java programmers.

*Executors* manage thread execution. At the top of the executor hierarchy is the *Executor* interface, which is used to initiate a thread. *ExecutorService* extends *Executor* and provides methods that manage execution. There are three implementations of *ExecutorService*: *ThreadPoolExecutor*, *ScheduledThreadPoolExecutor*, and *ForkJoinPool*. *java.util.concurrent* also defines the *Executors* utility class, which includes a number of static methods that simplify the creation of various executors.

Related to executors are the *Future* and *Callable* interfaces. A *Future* contains a value that is returned by a thread after it executes. Thus, its value becomes defined “in the future,” when the thread terminates. *Callable* defines a thread that returns a value.

*java.util.concurrent* defines several concurrent collection classes, including *ConcurrentHashMap*, *ConcurrentLinkedQueue*, and *CopyOnWriteArrayList*. These offer concurrent alternatives to their related classes defined by the Collections Framework.


To better handle thread timing, *java.util.concurrent* defines the *TimeUnit* enumeration.

Beginning with JDK 9, *java.util.concurrent* also includes a subsystem that offers a means by which the flow of data can be controlled. It is based on the *Flow* class and these nested interfaces: *Flow.Subscriber*, *Flow.Publisher*, *Flow.Processor*, and *Flow.Subscription*. Although a detailed discussion of the *Flow* subsystem is outside the focus of this chapter, here is a brief description. *Flow* and its nested interfaces support the *reactive streams* specification. This specification defines a

<table>
<thead>
<tr>
<th>Synchronizer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semaphore</td>
<td>Implements the classic semaphore.</td>
</tr>
<tr>
<td>CountDownLatch</td>
<td>Waits until a specified number of events have occurred.</td>
</tr>
<tr>
<td>CyclicBarrier</td>
<td>Enables a group of threads to wait at a predefined execution point.</td>
</tr>
<tr>
<td>Exchanger</td>
<td>Exchanges data between two threads.</td>
</tr>
<tr>
<td>Phaser</td>
<td>Synchronizes threads that advance through multiple phases of an operation.</td>
</tr>
</tbody>
</table>
means by which a consumer of data can prevent the producer of the data from overrunning the consumer’s ability to process the data. In this approach, data is produced by a publisher and consumed by a subscriber. Control is achieved by implementing a form of back pressure.

```java
java.util.concurrent.atomic
```

java.util.concurrent.atomic facilitates the use of variables in a concurrent environment. It provides a means of efficiently updating the value of a variable without the use of locks. This is accomplished through the use of classes, such as AtomicInteger and AtomicLong, and methods, such as compareAndSet(), decrementAndGet(), and getAndSet(). These methods execute as a single, non-interruptible operation.

```java
java.util.concurrent.locks
```

java.util.concurrent.locks provides an alternative to the use of synchronized methods. At the core of this alternative is the Lock interface, which defines the basic mechanism used to acquire and relinquish access to an object. The key methods are lock(), tryLock(), and unlock(). The advantage to using these methods is greater control over synchronization.

The remainder of this chapter takes a closer look at the constituents of the concurrent API.

## Using Synchronization Objects

Synchronization objects are supported by the Semaphore, CountDownLatch, CyclicBarrier, Exchanger, and Phaser classes. Collectively, they enable you to handle several formerly difficult synchronization situations with ease. They are also applicable to a wide range of programs—even those that contain only limited concurrency. Because the synchronization objects will be of interest to nearly all Java programs, each is examined here in some detail.

### Semaphore

The synchronization object that many readers will immediately recognize is Semaphore, which implements a classic semaphore. A semaphore controls access to a shared resource through the use of a counter. If the counter is greater than zero, then access is allowed. If it is zero, then access is denied. What the counter is counting are permits that allow access to the shared resource. Thus, to access the
resource, a thread must be granted a permit from the semaphore.

In general, to use a semaphore, the thread that wants access to the shared resource tries to acquire a permit. If the semaphore’s count is greater than zero, then the thread acquires a permit, which causes the semaphore’s count to be decremented. Otherwise, the thread will be blocked until a permit can be acquired. When the thread no longer needs access to the shared resource, it releases the permit, which causes the semaphore’s count to be incremented. If there is another thread waiting for a permit, then that thread will acquire a permit at that time. Java’s Semaphore class implements this mechanism.

Semaphore has the two constructors shown here:

Semaphore(int num)
Semaphore(int num, boolean how)

Here, num specifies the initial permit count. Thus, num specifies the number of threads that can access a shared resource at any one time. If num is one, then only one thread can access the resource at any one time. By default, waiting threads are granted a permit in an undefined order. By setting how to true, you can ensure that waiting threads are granted a permit in the order in which they requested access.

To acquire a permit, call the acquire() method, which has these two forms:

void acquire( ) throws InterruptedException
void acquire(int num) throws InterruptedException

The first form acquires one permit. The second form acquires num permits. Most often, the first form is used. If the permit cannot be granted at the time of the call, then the invoking thread suspends until the permit is available.

To release a permit, call release(), which has these two forms:

void release( )
void release(int num)

The first form releases one permit. The second form releases the number of permits specified by num.

To use a semaphore to control access to a resource, each thread that wants to use that resource must first call acquire() before accessing the resource. When the thread is done with the resource, it must call release(). Here is an example that illustrates the use of a semaphore:
// A simple semaphore example.

import java.util.concurrent.*;

class SemDemo {
    public static void main(String args[]) {
        Semaphore sem = new Semaphore(1);

        new Thread(new IncThread(sem, "A")).start();
        new Thread(new DecThread(sem, "B")).start();
    }
}

// A shared resource.
class Shared {
    static int count = 0;
}

// A thread of execution that increments count.
class IncThread implements Runnable {
    String name;
    Semaphore sem;

    IncThread(Semaphore s, String n) {
        sem = s;
        name = n;
    }

    public void run() {
        System.out.println("Starting " + name);

        try {
            // First, get a permit.
            System.out.println(name + " is waiting for a permit.");
            sem.acquire();
            System.out.println(name + " gets a permit.");

            // Now, access shared resource.
            for(int i=0; i < 5; i++) {
                Shared.count++;
                System.out.println(name + ": " + Shared.count);

                // Now, allow a context switch -- if possible.
                Thread.sleep(10);
            }
        }
    }
}
```java
} catch (InterruptedException exc) {
    System.out.println(exc);
}

// Release the permit.
System.out.println(name + " releases the permit.");
sem.release();
}
}

// A thread of execution that decrements count.
class DecThread implements Runnable {
    String name;
    Semaphore sem;

    DecThread(Semaphore s, String n) {
        sem = s;
        name = n;
    }

    public void run() {
        System.out.println("Starting " + name);

        try {
            // First, get a permit.
            System.out.println(name + " is waiting for a permit.");
            sem.acquire();
            System.out.println(name + " gets a permit.");

            // Now, access shared resource.
            for(int i=0; i < 5; i++) {
                Shared.count--;
                System.out.println(name + ": " + Shared.count);

                // Now, allow a context switch -- if possible.
                Thread.sleep(10);
            }
        } catch (InterruptedException exc) {
            System.out.println(exc);
        }

        // Release the permit.
        System.out.println(name + " releases the permit.");
        sem.release();
    }
}
```
The output from the program is shown here. (The precise order in which the threads execute may vary.)

```
Starting A
A is waiting for a permit.
A gets a permit.
A: 1
Starting B
B is waiting for a permit.
A: 2
A: 3
A: 4
A: 5
A releases the permit.
B gets a permit.
B: 4
B: 3
B: 2
B: 1
B: 0
B releases the permit.
```

The program uses a semaphore to control access to the `count` variable, which is a static variable within the `Shared` class. `Shared.count` is incremented five times by the `run()` method of `IncThread` and decremented five times by `DecThread`. To prevent these two threads from accessing `Shared.count` at the same time, access is allowed only after a permit is acquired from the controlling semaphore. After access is complete, the permit is released. In this way, only one thread at a time will access `Shared.count`, as the output shows.

In both `IncThread` and `DecThread`, notice the call to `sleep()` within `run()`. It is used to “prove” that accesses to `Shared.count` are synchronized by the semaphore. In `run()`, the call to `sleep()` causes the invoking thread to pause between each access to `Shared.count`. This would normally enable the second thread to run. However, because of the semaphore, the second thread must wait until the first has released the permit, which happens only after all accesses by the first thread are complete. Thus, `Shared.count` is incremented five times by `IncThread` and decremented five times by `DecThread`. The increments and decrements are not intermixed.

Without the use of the semaphore, accesses to `Shared.count` by both threads would have occurred simultaneously, and the increments and decrements would be
intermixed. To confirm this, try commenting out the calls to acquire() and release(). When you run the program, you will see that access to Shared.count is no longer synchronized, and each thread accesses it as soon as it gets a timeslice.

Although many uses of a semaphore are as straightforward as that shown in the preceding program, more intriguing uses are also possible. Here is an example. The following program reworks the producer/consumer program shown in Chapter 11 so that it uses two semaphores to regulate the producer and consumer threads, ensuring that each call to put() is followed by a corresponding call to get():

```java
// An implementation of a producer and consumer
// that use semaphores to control synchronization.

import java.util.concurrent.Semaphore;

class Q {
    int n;
```
// Start with consumer semaphore unavailable.
static Semaphore semCon = new Semaphore(0);
static Semaphore semProd = new Semaphore(1);

void get() {
    try {
        semCon.acquire();
    } catch(InterruptedException e) {
        System.out.println("InterruptedException caught");
    }

    System.out.println("Got: " + n);
    semProd.release();
}

void put(int n) {
    try {
        semProd.acquire();
    } catch(InterruptedException e) {
        System.out.println("InterruptedException caught");
    }

    this.n = n;
    System.out.println("Put: " + n);
    semCon.release();
}
class Producer implements Runnable {
    Q q;

    Producer(Q q) {
        this.q = q;
    }

    public void run() {
        for(int i=0; i < 20; i++) q.put(i);
    }
}

class Consumer implements Runnable {
    Q q;

    Consumer(Q q) {
        this.q = q;
    }

    public void run() {
        for(int i=0; i < 20; i++) q.get();
    }
}

class ProdCon {
    public static void main(String args[]) {
        Q q = new Q();
        new Thread(new Consumer(q), "Consumer").start();
        new Thread(new Producer(q), "Producer").start();
    }
}

A portion of the output is shown here:
As you can see, the calls to `put()` and `get()` are synchronized. That is, each call to `put()` is followed by a call to `get()` and no values are missed. Without the semaphores, multiple calls to `put()` would have occurred without matching calls to `get()`, resulting in values being missed. (To prove this, remove the semaphore code and observe the results.)

The sequencing of `put()` and `get()` calls is handled by two semaphores: `semProd` and `semCon`. Before `put()` can produce a value, it must acquire a permit from `semProd`. After it has set the value, it releases `semCon`. Before `get()` can consume a value, it must acquire a permit from `semCon`. After it consumes the value, it releases `semProd`. This “give and take” mechanism ensures that each call to `put()` must be followed by a call to `get()`.

Notice that `semCon` is initialized with no available permits. This ensures that `put()` executes first. The ability to set the initial synchronization state is one of the more powerful aspects of a semaphore.

**CountDownLatch**

Sometimes you will want a thread to wait until one or more events have occurred. To handle such a situation, the concurrent API supplies `CountDownLatch`. A `CountDownLatch` is initially created with a count of the number of events that must occur before the latch is released. Each time an event happens, the count is decremented. When the count reaches zero, the latch opens.

`CountDownLatch` has the following constructor:

```java
CountDownLatch(int num)
```
Here, \( num \) specifies the number of events that must occur in order for the latch to open.

To wait on the latch, a thread calls \texttt{await( )}, which has the forms shown here:

\[
\begin{align*}
\text{void await( ) throws InterruptedException} \\
\text{boolean await(long \textit{wait}, TimeUnit \textit{tu}) throws InterruptedException}
\end{align*}
\]

The first form waits until the count associated with the invoking \texttt{CountDownLatch} reaches zero. The second form waits only for the period of time specified by \( \textit{wait} \). The units represented by \( \textit{wait} \) are specified by \( \textit{tu} \), which is an object the \texttt{TimeUnit} enumeration. (\texttt{TimeUnit} is described later in this chapter.) It returns \texttt{false} if the time limit is reached and \texttt{true} if the countdown reaches zero.

To signal an event, call the \texttt{countDown( )} method, shown next:

\[
\text{void countDown( )}
\]

Each call to \texttt{countDown( )} decrements the count associated with the invoking object.

The following program demonstrates \texttt{CountDownLatch}. It creates a latch that requires five events to occur before it opens.
// An example of CountDownLatch.

import java.util.concurrent.CountDownLatch;

class CDLDemo {
    public static void main(String args[]) {
        CountDownLatch cdl = new CountDownLatch(5);

        System.out.println("Starting");

        new Thread(new MyThread(cdl)).start();

        try {
            cdl.await();
        } catch (InterruptedException exc) {
            System.out.println(exc);
        }

        System.out.println("Done");
    }
}

class MyThread implements Runnable {
    CountDownLatch latch;

    MyThread(CountDownLatch c) {
        latch = c;
    }

    public void run() {
        for(int i = 0; i<5; i++) {
            System.out.println(i);
            latch.countDown(); // decrement count
        }
    }
}

The output produced by the program is shown here:
Inside `main()`, a `CountDownLatch` called `cdl` is created with an initial count of five. Next, an instance of `MyThread` is created, which begins execution of a new thread. Notice that `cdl` is passed as a parameter to `MyThread`’s constructor and stored in the `latch` instance variable. Then, the main thread calls `await()` on `cdl`, which causes execution of the main thread to pause until `cdl`’s count has been decremented five times.

Inside the `run()` method of `MyThread`, a loop is created that iterates five times. With each iteration, the `countDown()` method is called on `latch`, which refers to `cdl` in `main()`. After the fifth iteration, the latch opens, which allows the main thread to resume.

`CountDownLatch` is a powerful yet easy-to-use synchronization object that is appropriate whenever a thread must wait for one or more events to occur.

**CyclicBarrier**

A situation not uncommon in concurrent programming occurs when a set of two or more threads must wait at a predetermined execution point until all threads in the set have reached that point. To handle such a situation, the concurrent API supplies the `CyclicBarrier` class. It enables you to define a synchronization object that suspends until the specified number of threads has reached the barrier point.

`CyclicBarrier` has the following two constructors:

```
CyclicBarrier(int numThreads)
CyclicBarrier(int numThreads, Runnable action)
```

Here, `numThreads` specifies the number of threads that must reach the barrier before execution continues. In the second form, `action` specifies a thread that will be executed when the barrier is reached.

Here is the general procedure that you will follow to use `CyclicBarrier`. First, create a `CyclicBarrier` object, specifying the number of threads that you will be waiting for. Next, when each thread reaches the barrier, have it call `await()` on that object. This will pause execution of the thread until all of the other threads also call `await()`. Once the specified number of threads has reached the barrier, `await()` will
return and execution will resume. Also, if you have specified an action, then that thread is executed.

The `await()` method has the following two forms:

```java
int await() throws InterruptedException, BrokenBarrierException
int await(long wait, TimeUnit tu)
```

The first form waits until all the threads have reached the barrier point. The second form waits only for the period of time specified by `wait`. The units represented by `wait` are specified by `tu`. Both forms return a value that indicates the order that the threads arrive at the barrier point. The first thread returns a value equal to the number of threads waited upon minus one. The last thread returns zero.

Here is an example that illustrates `CyclicBarrier`. It waits until a set of three threads has reached the barrier. When that occurs, the thread specified by `BarAction` executes.
// An example of CyclicBarrier.

import java.util.concurrent.*;

class BarDemo {
    public static void main(String args[]) {
        CyclicBarrier cb = new CyclicBarrier(3, new BarAction() );

        System.out.println("Starting");

        new Thread(new MyThread(cb, "A")).start();
        new Thread(new MyThread(cb, "B")).start();
        new Thread(new MyThread(cb, "C")).start();
    }
}

// A thread of execution that uses a CyclicBarrier.

class MyThread implements Runnable {
    CyclicBarrier cbar;
    String name;

    MyThread(CyclicBarrier c, String n) {
        cbar = c;
        name = n;
    }

    public void run() {
        System.out.println(name);

        try {
            cbar.await();
        } catch (BrokenBarrierException exc) {
            System.out.println(exc);
        } catch (InterruptedException exc) {
            System.out.println(exc);
        }
    }
}

// An object of this class is called when the
// CyclicBarrier ends.
class BarAction implements Runnable {
    public void run() {
        System.out.println("Barrier Reached!");
    }
}

The output is shown here. (The precise order in which the threads execute may vary.)

Starting
A
B
C
Barrier Reached!

A CyclicBarrier can be reused because it will release waiting threads each time the specified number of threads calls await(). For example, if you change main() in the preceding program so that it looks like this:

```java
public static void main(String args[]) {
    CyclicBarrier cb = new CyclicBarrier(3, new BarAction());

    System.out.println("Starting");

    new Thread(new MyThread(cb, "A")).start();
    new Thread(new MyThread(cb, "B")).start();
    new Thread(new MyThread(cb, "C")).start();
    new Thread(new MyThread(cb, "X")).start();
    new Thread(new MyThread(cb, "Y")).start();
    new Thread(new MyThread(cb, "Z")).start();
}
```

the following output will be produced. (The precise order in which the threads execute may vary.)
As the preceding example shows, the CyclicBarrier offers a streamlined solution to what was previously a complicated problem.

Exchanger

Perhaps the most interesting of the synchronization classes is Exchanger. It is designed to simplify the exchange of data between two threads. The operation of an Exchanger is astoundingly simple: it simply waits until two separate threads call its exchange() method. When that occurs, it exchanges the data supplied by the threads. This mechanism is both elegant and easy to use. Uses for Exchanger are easy to imagine. For example, one thread might prepare a buffer for receiving information over a network connection. Another thread might fill that buffer with the information from the connection. The two threads work together so that each time a new buffer is needed, an exchange is made.

Exchanger is a generic class that is declared as shown here:

Exchanger<V>

Here, V specifies the type of the data being exchanged.

The only method defined by Exchanger is exchange(), which has the two forms shown here:

V exchange(V objRef) throws InterruptedException
V exchange(V objRef, long wait, TimeUnit tu)
    throws InterruptedException, TimeoutException

Here, objRef is a reference to the data to exchange. The data received from the other thread is returned. The second form of exchange() allows a time-out period to be specified. The key point about exchange() is that it won’t succeed until it has been called on the same Exchanger object by two separate threads. Thus, exchange() synchronizes the exchange of the data.
Here is an example that demonstrates **Exchanger**. It creates two threads. One thread creates an empty buffer that will receive the data put into it by the second thread. In this case, the data is a string. Thus, the first thread exchanges an empty string for a full one.

```
// An example of Exchanger.

import java.util.concurrent.Exchanger;

class ExgrDemo {
    public static void main(String args[]) {
        Exchanger<String> exgr = new Exchanger<String>();

        new Thread(new UseString(exgr)).start();
        new Thread(new MakeString(exgr)).start();
    }
}

// A Thread that constructs a string.
class MakeString implements Runnable {
    Exchanger<String> ex;
    String str;

    MakeString(Exchanger<String> c) {
        ex = c;
        str = new String();
    }
}
```
public void run() {
    char ch = 'A';

    for(int i = 0; i < 3; i++) {

        // Fill Buffer
        for(int j = 0; j < 5; j++)
            str += ch++;

        try {
            // Exchange a full buffer for an empty one.
            str = ex.exchange(str);
        } catch(InterruptedException exc) {
            System.out.println(exc);
        }
    }
}

// A Thread that uses a string.
class UseString implements Runnable {
    Exchanger<String> ex;
    String str;
    UseString(Exchanger<String> c) {
        ex = c;
    }

    public void run() {

        for(int i=0; i < 3; i++) {
            try {
                // Exchange an empty buffer for a full one.
                str = ex.exchange(new String());
                System.out.println("Got: " + str);
            } catch(InterruptedException exc) {
                System.out.println(exc);
            }
        }
    }
}

Here is the output produced by the program:
In the program, the `main()` method creates an `Exchanger` for strings. This object is then used to synchronize the exchange of strings between the `MakeString` and `UseString` classes. The `MakeString` class fills a string with data. The `UseString` exchanges an empty string for a full one. It then displays the contents of the newly constructed string. The exchange of empty and full buffers is synchronized by the `exchange()` method, which is called by both classes’ `run()` method.

**Phaser**

Another synchronization class is called `Phaser`. Its primary purpose is to enable the synchronization of threads that represent one or more phases of activity. For example, you might have a set of threads that implement three phases of an order-processing application. In the first phase, separate threads are used to validate customer information, check inventory, and confirm pricing. When that phase is complete, the second phase has two threads that compute shipping costs and all applicable tax. After that, a final phase confirms payment and determines estimated shipping time. In the past, to synchronize the multiple threads that comprise this scenario would require a bit of work on your part. With the inclusion of `Phaser`, the process is now much easier.

To begin, it helps to know that a `Phaser` works a bit like a `CyclicBarrier`, described earlier, except that it supports multiple phases. As a result, `Phaser` lets you define a synchronization object that waits until a specific phase has completed. It then advances to the next phase, again waiting until that phase concludes. It is important to understand that `Phaser` can also be used to synchronize only a single phase. In this regard, it acts much like a `CyclicBarrier`. However, its primary use is to synchronize multiple phases.

`Phaser` defines four constructors. Here are the two used in this section:

```
Phaser()
Phaser(int numParties)
```

The first creates a phaser that has a registration count of zero. The second sets the registration count to `numParties`. The term `party` is often applied to the objects that register with a phaser. Although typically there is a one-to-correspondence between the number of registrants and the number of threads being synchronized, this is not required. In both cases, the current phase is zero. That is, when a `Phaser` is created,
it is initially at phase zero.

In general, here is how you use Phaser. First, create a new instance of Phaser. Next, register one or more parties with the phaser, either by calling `register()` or by specifying the number of parties in the constructor. For each registered party, have the phaser wait until all registered parties complete a phase. A party signals this by calling one of a variety of methods supplied by Phaser, such as `arrive()` or `arriveAndAwaitAdvance()`. After all parties have arrived, the phase is complete, and the phaser can move on to the next phase (if there is one), or terminate. The following sections explain the process in detail.

To register parties after a Phaser has been constructed, call `register()`. It is shown here:

```
int register()
```

It returns the phase number of the phase to which it is registered.

To signal that a party has completed a phase, it must call `arrive()` or some variation of `arrive()`. When the number of arrivals equals the number of registered parties, the phase is completed and the Phaser moves on to the next phase (if there is one). The `arrive()` method has this general form:

```
int arrive()
```

This method signals that a party (normally a thread of execution) has completed some task (or portion of a task). It returns the current phase number. If the phaser has been terminated, then it returns a negative value. The `arrive()` method does not suspend execution of the calling thread. This means that it does not wait for the phase to be completed. This method should be called only by a registered party.

If you want to indicate the completion of a phase and then wait until all other registrants have also completed that phase, use `arriveAndAwaitAdvance()`. It is shown here:

```
int arriveAndAwaitAdvance()
```

It waits until all parties have arrived. It returns the next phase number or a negative value if the phaser has been terminated. This method should be called only by a registered party.

A thread can arrive and then deregister itself by calling `arriveAndDeregister()`. It is shown here:

```
int arriveAndDeregister()
```
It returns the current phase number or a negative value if the phaser has been terminated. It does not wait until the phase is complete. This method should be called only by a registered party.

To obtain the current phase number, call `getPhase()`, which is shown here:

```java
final int getPhase()
```

When a `Phaser` is created, the first phase will be 0, the second phase 1, the third phase 2, and so on. A negative value is returned if the invoking `Phaser` has been terminated.

Here is an example that shows `Phaser` in action. It creates three threads, each of which have three phases. It uses a `Phaser` to synchronize each phase.

// An example of Phaser.

```java
import java.util.concurrent.*;

class PhaserDemo {
    public static void main(String args[]) {
        Phaser phsr = new Phaser(1);
        int curPhase;

        System.out.println("Starting");

        new Thread(new MyThread(phsr, "A")).start();
        new Thread(new MyThread(phsr, "B")).start();
        new Thread(new MyThread(phsr, "C")).start();

        // Wait for all threads to complete phase one.
        curPhase = phsr.getPhase();
        phsr.arriveAndAwaitAdvance();
        System.out.println("Phase " + curPhase + " Complete");

        // Wait for all threads to complete phase two.
        curPhase = phsr.getPhase();
        phsr.arriveAndAwaitAdvance();
        System.out.println("Phase " + curPhase + " Complete");

        curPhase = phsr.getPhase();
        phsr.arriveAndAwaitAdvance();
        System.out.println("Phase " + curPhase + " Complete");
```
// Deregister the main thread.
phsr.arriveAndDeregister();

if(phsr.isTerminated())
    System.out.println("The Phaser is terminated");
}

// A thread of execution that uses a Phaser.
class MyThread implements Runnable {
    Phaser phsr;
    String name;

    MyThread(Phaser p, String n) {
        phsr = p;
        name = n;
        phsr.register();
    }

    public void run() {

System.out.println("Thread " + name + " Beginning Phase One");
phsr.arriveAndAwaitAdvance(); // Signal arrival.

// Pause a bit to prevent jumbled output. This is for illustration
// only. It is not required for the proper operation of the phaser.
try {
    Thread.sleep(100);
} catch(InterruptedException e) {
    System.out.println(e);
}

System.out.println("Thread " + name + " Beginning Phase Two");
phsr.arriveAndAwaitAdvance(); // Signal arrival.

// Pause a bit to prevent jumbled output. This is for illustration
// only. It is not required for the proper operation of the phaser.
try {
    Thread.sleep(100);
} catch(InterruptedException e) {
    System.out.println(e);
}

System.out.println("Thread " + name + " Beginning Phase Three");
phsr.arriveAndDeregister(); // Signal arrival and deregister.
}

Sample output is shown here. (Your output may vary.)

Starting
Thread A Beginning Phase One
Thread C Beginning Phase One
Thread B Beginning Phase One

Phase 0 Complete
Thread B Beginning Phase Two
Thread C Beginning Phase Two
Thread A Beginning Phase Two
Phase 1 Complete
Thread C Beginning Phase Three
Thread B Beginning Phase Three
Thread A Beginning Phase Three
Phase 2 Complete
The Phaser is terminated
Let’s look closely at the key sections of the program. First, in `main()`, a `Phaser` called `phsr` is created with an initial party count of 1 (which corresponds to the main thread). Then three threads are started by creating three `MyThread` objects. Notice that `MyThread` is passed a reference to `phsr` (the phaser). The `MyThread` objects use this phaser to synchronize their activities. Next, `main()` calls `getPhase()` to obtain the current phase number (which is initially zero) and then calls `arriveAndAwaitAdvance()`. This causes `main()` to suspend until phase zero has completed. This won’t happen until all `MyThreads` also call `arriveAndAwaitAdvance()`. When this occurs, `main()` will resume execution, at which point it displays that phase zero has completed, and it moves on to the next phase. This process repeats until all three phases have finished. Then, `main()` calls `arriveAndDeregister()`. At that point, all three `MyThreads` have also deregistered. Since this results in there being no registered parties when the phaser advances to the next phase, the phaser is terminated.

Now look at `MyThread`. First, notice that the constructor is passed a reference to the phaser that it will use and then registers with the new thread as a party on that phaser. Thus, each new `MyThread` becomes a party registered with the passed-in phaser. Also notice that each thread has three phases. In this example, each phase consists of a placeholder that simply displays the name of the thread and what it is doing. Obviously, in real-world code, the thread would be performing more meaningful actions. Between the first two phases, the thread calls `arriveAndAwaitAdvance()`. Thus, each thread waits until all threads have completed the phase (and the main thread is ready). After all threads have arrived (including the main thread), the phaser moves on to the next phase. After the third phase, each thread deregisters itself with a call to `arriveAndDeregister()`. As the comments in `MyThread` explain, the calls to `sleep()` are used for the purposes of illustration to ensure that the output is not jumbled because of the multithreading. They are not needed to make the phaser work properly. If you remove them, the output may look a bit jumbled, but the phases will still be synchronized correctly.

One other point: Although the preceding example used three threads that were all of the same type, this is not a requirement. Each party that uses a phaser can be unique, with each performing some separate task.

It is possible to take control of precisely what happens when a phase advance occurs. To do this, you must override the `onAdvance()` method. This method is called by the run time when a `Phaser` advances from one phase to the next. It is shown here:

```java
protected boolean onAdvance(int phase, int numParties)
```

Here, `phase` will contain the current phase number prior to being incremented and
numParties will contain the number of registered parties. To terminate the phaser, `onAdvance()` must return true. To keep the phaser alive, `onAdvance()` must return false. The default version of `onAdvance()` returns true (thus terminating the phaser) when there are no registered parties. As a general rule, your override should also follow this practice.

One reason to override `onAdvance()` is to enable a phaser to execute a specific number of phases and then stop. The following example gives you the flavor of this usage. It creates a class called MyPhaser that extends Phaser so that it will run a specified number of phases. It does this by overriding the `onAdvance()` method. The MyPhaser constructor accepts one argument, which specifies the number of phases to execute. Notice that MyPhaser automatically registers one party. This behavior is useful in this example, but the needs of your own applications may differ.
// Extend Phaser and override onAdvance() so that only a specific
// number of phases are executed.

import java.util.concurrent.*;

// Extend MyPhaser to allow only a specific number of phases
// to be executed.
class MyPhaser extends Phaser {
    int numPhases;

    MyPhaser(int parties, int phaseCount) {
        super(parties);
        numPhases = phaseCount - 1;
    }

    // Override onAdvance() to execute the specified
    // number of phases.
    protected boolean onAdvance(int p, int regParties) {
        // This println() statement is for illustration only.
        // Normally, onAdvance() will not display output.
        System.out.println("Phase " + p + " completed.\n");

        // If all phases have completed, return true
        if(p == numPhases || regParties == 0) return true;

        // Otherwise, return false.
        return false;
    }
}

class PhaserDemo2 {
    public static void main(String args[]) {
        MyPhaser phsr = new MyPhaser(1, 4);

        System.out.println("Starting\n");

        new Thread(new MyThread(phsr, "A")).start();
        new Thread(new MyThread(phsr, "B")).start();
        new Thread(new MyThread(phsr, "C")).start();
// Wait for the specified number of phases to complete.
while(!phsr.isTerminated()) {
    phsr.arriveAndAwaitAdvance();
}

System.out.println("The Phaser is terminated");
}

// A thread of execution that uses a Phaser.
class MyThread implements Runnable {
    Phaser phsr;
    String name;

    MyThread(Phaser p, String n) {
        phsr = p;
        name = n;
        phsr.register();
    }

    public void run() {
        while(!phsr.isTerminated()) {
            System.out.println("Thread " + name + " Beginning Phase " +
                              phsr.getPhase());

            phsr.arriveAndAwaitAdvance();

            // Pause a bit to prevent jumbled output. This is for illustration
            // only. It is not required for the proper operation of the phaser.
            try {
                Thread.sleep(100);
            } catch(InterruptedException e) {
                System.out.println(e);
            }
        }
    }
}

The output from the program is shown here:
Inside `main()` , one instance of `Phaser` is created. It is passed 4 as an argument, which means that it will execute four phases and then stop. Next, three threads are created and then the following loop is entered:

```
// Wait for the specified number of phases to complete.
while(!phsr.isTerminated()) {
    phsr.arriveAndAwaitAdvance();
}
```

This loop simply calls `arriveAndAwaitAdvance()` until the phaser is terminated. The phaser won’t terminate until the specified number of phases have been executed. In this case, the loop continues to execute until four phases have run. Next, notice that the threads also call `arriveAndAwaitAdvance()` within a loop that runs until the phaser is terminated. This means that they will execute until the specified number of phases has been completed.

Now, look closely at the code for `onAdvance()` . Each time `onAdvance()` is called, it is passed the current phase and the number of registered parties. If the current phase equals the specified phase, or if the number of registered parties is zero, `onAdvance()` returns `true` , thus stopping the phaser. This is accomplished with
As you can see, very little code is needed to accommodate the desired outcome.

Before moving on, it is useful to point out that you don’t necessarily need to explicitly extend Phaser as the previous example does to simply override onAdvance( ). In some cases, more compact code can be created by using an anonymous inner class to override onAdvance( ).

Phaser has additional capabilities that may be of use in your applications. You can wait for a specific phase by calling awaitAdvance( ), which is shown here:

```java
int awaitAdvance(int phase)
```

Here, phase indicates the phase number on which awaitAdvance( ) will wait until a transition to the next phase takes place. It will return immediately if the argument passed to phase is not equal to the current phase. It will also return immediately if the phaser is terminated. However, if phase is passed the current phase, then it will wait until the phase increments. This method should be called only by a registered party. There is also an interruptible version of this method called awaitAdvanceInterruptibly( ).

To register more than one party, call bulkRegister( ). To obtain the number of registered parties, call getRegisteredParties( ). You can also obtain the number of arrived parties and unarrived parties by calling getArrivedParties( ) and getUnarrivedParties( ), respectively. To force the phaser to enter a terminated state, call forceTermination( ).

Phaser also lets you create a tree of phasers. This is supported by two additional constructors, which let you specify the parent, and the getParent( ) method.

### Using an Executor

The concurrent API supplies a feature called an executor that initiates and controls the execution of threads. As such, an executor offers an alternative to managing threads through the Thread class.

At the core of an executor is the Executor interface. It defines the following method:

```java
void execute(Runnable thread)
```
The thread specified by *thread* is executed. Thus, *execute()* starts the specified thread.

The **ExecutorService** interface extends **Executor** by adding methods that help manage and control the execution of threads. For example, **ExecutorService** defines *shutdown()*, shown here, which stops the invoking **ExecutorService**.

```java
void shutdown()
```

**ExecutorService** also defines methods that execute threads that return results, that execute a set of threads, and that determine the shutdown status. We will look at several of these methods a little later.

Also defined is the interface **ScheduledExecutorService**, which extends **ExecutorService** to support the scheduling of threads.

The concurrent API defines three predefined executor classes: **ThreadPoolExecutor** and **ScheduledThreadPoolExecutor**, and **ForkJoinPool**.

**ThreadPoolExecutor** implements the **Executor** and **ExecutorService** interfaces and provides support for a managed pool of threads.

**ScheduledThreadPoolExecutor** also implements the **ScheduledExecutorService** interface to allow a pool of threads to be scheduled. **ForkJoinPool** implements the **Executor** and **ExecutorService** interfaces and is used by the Fork/Join Framework. It is described later in this chapter.

A thread pool provides a set of threads that is used to execute various tasks. Instead of each task using its own thread, the threads in the pool are used. This reduces the overhead associated with creating many separate threads. Although you can use **ThreadPoolExecutor** and **ScheduledThreadPoolExecutor** directly, most often you will want to obtain an executor by calling one of the following static factory methods defined by the **Executors** utility class. Here are some examples:

```java
static ExecutorService newCachedThreadPool()
static ExecutorService newFixedThreadPool(int numThreads)
static ScheduledExecutorService newScheduledThreadPool(int numThreads)
```

**newCachedThreadPool()** creates a thread pool that adds threads as needed but reuses threads if possible. **newFixedThreadPool()** creates a thread pool that consists of a specified number of threads. **newScheduledThreadPool()** creates a thread pool that supports thread scheduling. Each returns a reference to an **ExecutorService** that can be used to manage the pool.

**A Simple Executor Example**
Before going any further, a simple example that uses an executor will be of value. The following program creates a fixed thread pool that contains two threads. It then uses that pool to execute four tasks. Thus, four tasks share the two threads that are in the pool. After the tasks finish, the pool is shut down and the program ends.
// A simple example that uses an Executor.

import java.util.concurrent.*;

class SimpExec {
    public static void main(String args[]) {
        CountDownLatch cdl = new CountDownLatch(5);
        CountDownLatch cdll = new CountDownLatch(5);
        CountDownLatch cdls = new CountDownLatch(5);
        CountDownLatch cdld = new CountDownLatch(5);
        ExecutorService es = Executors.newFixedThreadPool(2);

        System.out.println("Starting");

        // Start the threads.
        es.execute(new MyThread(cdl, "A"));
        es.execute(new MyThread(cdll, "B"));
        es.execute(new MyThread(cdls, "C"));
        es.execute(new MyThread(cdld, "D"));

        try {
            cdl.await();
            cdll.await();
            cdls.await();
            cdld.await();
        } catch (InterruptedException exc) {
            System.out.println(exc);
        }

        es.shutdown();
        System.out.println("Done");
    }
}

class MyThread implements Runnable {
    String name;
    CountDownLatch latch;

    MyThread(CountDownLatch c, String n) {
        latch = c;
        name = n;
    }
}
The output from the program is shown here. (The precise order in which the threads execute may vary.)

Starting
A: 0
A: 1
A: 2
A: 3
A: 4
C: 0
C: 1
C: 2
C: 3
C: 4
D: 0
D: 1
D: 2
D: 3
D: 4
B: 0
B: 1
B: 2
B: 3
B: 4
Done

As the output shows, even though the thread pool contains only two threads, all four tasks are still executed. However, only two can run at the same time. The others must wait until one of the pooled threads is available for use.

The call to shutdown() is important. If it were not present in the program, then the program would not terminate because the executor would remain active. To try this for yourself, simply comment out the call to shutdown() and observe the result.

Using Callable and Future
One of the most interesting features of the concurrent API is the Callable interface. This interface represents a thread that returns a value. An application can use Callable objects to compute results that are then returned to the invoking thread. This is a powerful mechanism because it facilitates the coding of many types of numerical computations in which partial results are computed simultaneously. It can also be used to run a thread that returns a status code that indicates the successful completion of the thread.

Callable is a generic interface that is defined like this:

```java
interface Callable<V>
```

Here, `V` indicates the type of data returned by the task. Callable defines only one method, `call()`, which is shown here:

```java
V call() throws Exception
```

Inside `call()`, you define the task that you want performed. After that task completes, you return the result. If the result cannot be computed, `call()` must throw an exception.

A Callable task is executed by an ExecutorService, by calling its `submit()` method. There are three forms of `submit()`, but only one is used to execute a Callable. It is shown here:

```java
<T> Future<T> submit(Callable<T> task)
```

Here, `task` is the Callable object that will be executed in its own thread. The result is returned through an object of type Future.

Future is a generic interface that represents the value that will be returned by a Callable object. Because this value is obtained at some future time, the name Future is appropriate. Future is defined like this:

```java
interface Future<V>
```

Here, `V` specifies the type of the result.

To obtain the returned value, you will call Future’s `get()` method, which has these two forms:

```java
V get()  
    throws InterruptedException, ExecutionException
V get(long wait, TimeUnit tu)
```
The first form waits for the result indefinitely. The second form allows you to specify a timeout period in \textit{wait}. The units of \textit{wait} are passed in \textit{tu}, which is an object of the \texttt{TimeUnit} enumeration, described later in this chapter.

The following program illustrates \texttt{Callable} and \texttt{Future} by creating three tasks that perform three different computations. The first returns the summation of a value, the second computes the length of the hypotenuse of a right triangle given the length of its sides, and the third computes the factorial of a value. All three computations occur simultaneously.

```java
// An example that uses a Callable.

import java.util.concurrent.*;

class CallableDemo {
    public static void main(String args[]) {
        ExecutorService es = Executors.newFixedThreadPool(3);
        Future<Integer> f;
        Future<Double> f2;
        Future<Integer> f3;

        System.out.println("Starting");
    }
}
```
f = es.submit(new Sum(10));
f2 = es.submit(new Hypot(3, 4));
f3 = es.submit(new Factorial(5));

try {
    System.out.println(f.get());
    System.out.println(f2.get());
    System.out.println(f3.get());
} catch (InterruptedException exc) {
    System.out.println(exc);
}
catch (ExecutionException exc) {
    System.out.println(exc);
}

es.shutdown();
System.out.println("Done");

// Following are three computational threads.

class Sum implements Callable<Integer> {
    int stop;

    Sum(int v) { stop = v; }

    public Integer call() {
        int sum = 0;
        for(int i = 1; i <= stop; i++) {
            sum += i;
        }
        return sum;
    }
}
The TimeUnit Enumeration

The concurrent API defines several methods that take an argument of type `TimeUnit`, which indicates a time-out period. `TimeUnit` is an enumeration that is used to specify the granularity (or resolution) of the timing. `TimeUnit` is defined within `java.util.concurrent`. It can be one of the following values:

DAYS

```java
class Hypot implements Callable<Double> {
    double side1, side2;

    Hypot(double s1, double s2) {
        side1 = s1;
        side2 = s2;
    }

    public Double call() {
        return Math.sqrt((side1*side1) + (side2*side2));
    }
}

class Factorial implements Callable<Integer> {
    int stop;

    Factorial(int v) { stop = v; }

    public Integer call() {
        int fact = 1;
        for(int i = 2; i <= stop; i++) {
            fact *= i;
        }
        return fact;
    }
}

The output is shown here:

Starting
55
5.0
120
Done
```
Although `TimeUnit` lets you specify any of these values in calls to methods that take a timing argument, there is no guarantee that the system is capable of the specified resolution.

Here is an example that uses `TimeUnit`. The `CallableDemo` class, shown in the previous section, is modified as shown next to use the second form of `get()` that takes a `TimeUnit` argument.

```java
try {
    System.out.println(f.get(10, TimeUnit.MILLISECONDS));
    System.out.println(f2.get(10, TimeUnit.MILLISECONDS));
    System.out.println(f3.get(10, TimeUnit.MILLISECONDS));
} catch (InterruptedException exc) {
    System.out.println(exc);
}
```

In this version, no call to `get()` will wait more than 10 milliseconds.

The `TimeUnit` enumeration defines various methods that convert between units. These are shown here:

```java
long convert(long tval, TimeUnit tu)
long toMicros(long tval)
long toMillis(long tval)
long toNanos(long tval)
long toSeconds(long tval)
long toDays(long tval)
long toHours(long tval)
long toMinutes(long tval)
```

The `convert()` method converts `tval` into the specified unit and returns the result.
The `to` methods perform the indicated conversion and return the result. JDK 9 adds the methods `toChronoUnit()` and `of()`, which convert between `java.time.temporal.ChronoUnits` and `TimeUnits`.

`TimeUnit` also defines the following timing methods:

```java
void sleep(long delay) throws InterruptedExecution
void timedJoin(Thread thrd, long delay) throws InterruptedExecution
void timedWait(Object obj, long delay) throws InterruptedExecution
```

Here, `sleep()` pauses execution for the specified delay period, which is specified in terms of the invoking enumeration constant. It translates into a call to `Thread.sleep()`. The `timedJoin()` method is a specialized version of `Thread.join()` in which `thrd` pauses for the time period specified by `delay`, which is described in terms of the invoking time unit. The `timedWait()` method is a specialized version of `Object.wait()` in which `obj` is waited on for the period of time specified by `delay`, which is described in terms of the invoking time unit.

### The Concurrent Collections

As explained, the concurrent API defines several collection classes that have been engineered for concurrent operation. They include:

- `ArrayBlockingQueue`
- `ConcurrentHashMap`
- `ConcurrentLinkedDeque`
- `ConcurrentLinkedQueue`
- `ConcurrentSkipListMap`
- `ConcurrentSkipListSet`
- `CopyOnWriteArrayList`
- `CopyOnWriteArraySet`
- `DelayQueue`
- `LinkedBlockingDeque`
- `LinkedBlockingQueue`
- `LinkedTransferQueue`
- `PriorityBlockingQueue`
- `SynchronousQueue`

These offer concurrent alternatives to their related classes defined by the Collections Framework. These collections work much like the other collections except that they provide concurrency support. Programmers familiar with the Collections Framework will have no trouble using these concurrent collections.
Locks

The java.util.concurrent.locks package provides support for locks, which are objects that offer an alternative to using synchronized to control access to a shared resource. In general, here is how a lock works. Before accessing a shared resource, the lock that protects that resource is acquired. When access to the resource is complete, the lock is released. If a second thread attempts to acquire the lock when it is in use by another thread, the second thread will suspend until the lock is released. In this way, conflicting access to a shared resource is prevented.

Locks are particularly useful when multiple threads need to access the value of shared data. For example, an inventory application might have a thread that first confirms that an item is in stock and then decreases the number of items on hand as each sale occurs. If two or more of these threads are running, then without some form of synchronization, it would be possible for one thread to be in the middle of a transaction when the second thread begins its transaction. The result could be that both threads would assume that adequate inventory exists, even if there is only sufficient inventory on hand to satisfy one sale. In this type of situation, a lock offers a convenient means of handling the needed synchronization.

The Lock interface defines a lock. The methods defined by Lock are shown in Table 28-1. In general, to acquire a lock, call lock(). If the lock is unavailable, lock( ) will wait. To release a lock, call unlock(). To see if a lock is available, and to acquire it if it is, call tryLock( ). This method will not wait for the lock if it is unavailable. Instead, it returns true if the lock is acquired and false otherwise. The newCondition( ) method returns a Condition object associated with the lock. Using a Condition, you gain detailed control of the lock through methods such as await( ) and signal( ), which provide functionality similar to Object.wait( ) and Object.notify( ).
Table 28-1  The Lock Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void lock( )</td>
<td>Waits until the invoking lock can be acquired.</td>
</tr>
<tr>
<td>void lockInterruptibly( )</td>
<td>Waits until the invoking lock can be acquired, unless interrupted.</td>
</tr>
<tr>
<td>throws InterruptedException</td>
<td></td>
</tr>
<tr>
<td>Condition newCondition( )</td>
<td>Returns a <strong>Condition</strong> object that is associated with the invoking lock.</td>
</tr>
<tr>
<td>boolean tryLock( )</td>
<td>Attempts to acquire the lock. This method will not wait if the lock is unavailable. Instead, it returns <strong>true</strong> if the lock has been acquired and <strong>false</strong> if the lock is currently in use by another thread.</td>
</tr>
<tr>
<td>boolean tryLock(long wait, TimeUnit tu)</td>
<td>Attempts to acquire the lock. If the lock is unavailable, this method will wait no longer than the period specified by <em>wait</em>, which is in <em>tu</em> units. It returns <strong>true</strong> if the lock has been acquired and <strong>false</strong> if the lock cannot be acquired within the specified period.</td>
</tr>
<tr>
<td>throws InterruptedException</td>
<td></td>
</tr>
<tr>
<td>void unlock( )</td>
<td>Releases the lock.</td>
</tr>
</tbody>
</table>

*java.util.concurrent.locks* supplies an implementation of *Lock* called *ReentrantLock*. *ReentrantLock* implements a *reentrant lock*, which is a lock that can be repeatedly entered by the thread that currently holds the lock. Of course, in the case of a thread reentering a lock, all calls to *lock( )* must be offset by an equal number of calls to *unlock( )* . Otherwise, a thread seeking to acquire the lock will suspend until the lock is not in use.

The following program demonstrates the use of a lock. It creates two threads that access a shared resource called *Shared.count*. Before a thread can access *Shared.count*, it must obtain a lock. After obtaining the lock, *Shared.count* is incremented and then, before releasing the lock, the thread sleeps. This causes the second thread to attempt to obtain the lock. However, because the lock is still held by the first thread, the second thread must wait until the first thread stops sleeping and releases the lock. The output shows that access to *Shared.count* is, indeed, synchronized by the lock.
// A simple lock example.

import java.util.concurrent.locks.*;

class LockDemo {

    public static void main(String args[]) {
        ReentrantLock lock = new ReentrantLock();

        new Thread(new LockThread(lock, "A")).start();
        new Thread(new LockThread(lock, "B")).start();
    }
}

// A shared resource.
class Shared {
    static int count = 0;
}

// A thread of execution that increments count.
class LockThread implements Runnable {
    String name;
    ReentrantLock lock;

    LockThread(ReentrantLock lk, String n) {
        lock = lk;
        name = n;
    }

    public void run() {
        System.out.println("Starting " + name);
    }
}
try {
    // First, lock count.
    System.out.println(name + " is waiting to lock count.");
    lock.lock();
    System.out.println(name + " is locking count.");
    Shared.count++;
    System.out.println(name + ": " + Shared.count);

    // Now, allow a context switch -- if possible.
    System.out.println(name + " is sleeping.");
    Thread.sleep(1000);
} catch (InterruptedException exc) {
    System.out.println(exc);
} finally {
    // Unlock
    System.out.println(name + " is unlocking count.");
    lock.unlock();
}

The output is shown here. (The precise order in which the threads execute may vary.)

Starting A
A is waiting to lock count.
A is locking count.
A: 1
A is sleeping.
Starting B
B is waiting to lock count.
A is unlocking count.
B is locking count.
B: 2
B is sleeping.
B is unlocking count.

java.util.concurrent.locks also defines the ReadWriteLock interface. This interface specifies a lock that maintains separate locks for read and write access. This enables multiple locks to be granted for readers of a resource as long as the resource is not being written. ReentrantReadWriteLock provides an implementation of ReadWriteLock.
NOTE There is a specialized lock called StampedLock. It does not implement the Lock or ReadWriteLock interfaces. It does, however, provide a mechanism that enables aspects of it to be used like a Lock or ReadWriteLock.

Atomic Operations

java.util.concurrent.atomic offers an alternative to the other synchronization features when reading or writing the value of some types of variables. This package offers methods that get, set, or compare the value of a variable in one uninterruptible (that is, atomic) operation. This means that no lock or other synchronization mechanism is required.

Atomic operations are accomplished through the use of classes, such as AtomicInteger and AtomicLong, and methods such as get(), set(), compareAndSet(), decrementAndGet(), and getAndSet(), which perform the action indicated by their names.

Here is an example that demonstrates how access to a shared integer can be synchronized by the use of AtomicInteger:
In the program, a static `AtomicInteger` named `ai` is created by `Shared`. Then, three threads of type `AtomThread` are created. Inside `run()`, `Shared.ai` is modified by calling `getAndSet()`. This method returns the previous value and then sets the value to the one passed as an argument. The use of `AtomicInteger` prevents two threads from writing to `ai` at the same time.

In general, the atomic operations offer a convenient (and possibly more efficient) alternative to the other synchronization mechanisms when only a single variable is involved. Among other features, `java.util.concurrent.atomic` also provides four
classes that support lock-free cumulative operations. These are `DoubleAccumulator`, `DoubleAdder`, `LongAccumulator`, and `LongAdder`. The accumulator classes support a series of user-specified operations. The adder classes maintain a cumulative sum.

**Parallel Programming via the Fork/Join Framework**

In recent years, an important trend has emerged in software development: *parallel programming*. Parallel programming is the name commonly given to the techniques that take advantage of computers that contain two or more processors (multicore). As most readers will know, multicore computers have become commonplace. The advantage that multi-processor environments offer is the ability to significantly increase program performance. As a result, there had been a growing need for a mechanism that gives Java programmers a simple, yet effective way to make use of multiple processors in a clean, scalable manner. To answer this need, JDK 7 added several new classes and interfaces that support parallel programming. They are commonly referred to as the *Fork/Join Framework*. The Fork/Join Framework is defined in the `java.util.concurrent` package.

The Fork/Join Framework enhances multithreaded programming in two important ways. First, it simplifies the creation and use of multiple threads. Second, it automatically makes use of multiple processors. In other words, by using the Fork/Join Framework you enable your applications to automatically scale to make use of the number of available processors. These two features make the Fork/Join Framework the recommended approach to multithreading when parallel processing is desired.

Before continuing, it is important to point out the distinction between traditional multithreading and parallel programming. In the past, most computers had a single CPU and multithreading was primarily used to take advantage of idle time, such as when a program is waiting for user input. Using this approach, one thread can execute while another is waiting. In other words, on a single-CPU system, multithreading is used to allow two or more tasks to share the CPU. This type of multithreading is typically supported by an object of type `Thread` (as described in Chapter 11). Although this type of multithreading will always remain quite useful, it was not optimized for situations in which two or more CPUs are available (multicore computers).

When multiple CPUs are present, a second type of multithreading capability that supports true parallel execution is required. With two or more CPUs, it is possible to execute portions of a program simultaneously, with each part executing on its own
CPU. This can be used to significantly speed up the execution of some types of operations, such as sorting, transforming, or searching a large array. In many cases, these types of operations can be broken down into smaller pieces (each acting on a portion of the array), and each piece can be run on its own CPU. As you can imagine, the gain in efficiency can be enormous. Simply put: Parallel programming will be part of nearly every programmer’s future because it offers a way to dramatically improve program performance.

The Main Fork/Join Classes

The Fork/Join Framework is packaged in java.util.concurrent. At the core of the Fork/Join Framework are the following four classes:

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ForkJoinTask&lt;V&gt;</td>
<td>An abstract class that defines a task</td>
</tr>
<tr>
<td>ForkJoinPool</td>
<td>Manages the execution of ForkJoinTasks</td>
</tr>
<tr>
<td>RecursiveAction</td>
<td>A subclass of ForkJoinTask&lt;V&gt; for tasks that do not return values</td>
</tr>
<tr>
<td>RecursiveTask&lt;V&gt;</td>
<td>A subclass of ForkJoinTask&lt;V&gt; for tasks that return values</td>
</tr>
</tbody>
</table>

Here is how they relate. A ForkJoinPool manages the execution of ForkJoinTasks. ForkJoinTask is an abstract class that is extended by the abstract classes RecursiveAction and RecursiveTask. Typically, your code will extend these classes to create a task. Before looking at the process in detail, an overview of the key aspects of each class will be helpful.

NOTE The class CountedCompleter also extends ForkJoinTask. However, a discussion of CountedCompleter is beyond the scope of this book.

ForkJoinTask<V>

ForkJoinTask<V> is an abstract class that defines a task that can be managed by a ForkJoinPool. The type parameter V specifies the result type of the task. ForkJoinTask differs from Thread in that ForkJoinTask represents lightweight abstraction of a task, rather than a thread of execution. ForkJoinTasks are executed by threads managed by a thread pool of type ForkJoinPool. This mechanism allows a large number of tasks to be managed by a small number of actual threads. Thus, ForkJoinTasks are very efficient when compared to threads.

ForkJoinTask defines many methods. At the core are fork() and join(), shown here:

```java
final ForkJoinTask<V> fork()
```
The **fork()** method submits the invoking task for asynchronous execution of the invoking task. This means that the thread that calls **fork()** continues to run. The **fork()** method returns `this` after the task is scheduled for execution. Prior to JDK 8, **fork()** could be executed only from within the computational portion of another **ForkJoinTask**, which is running within a **ForkJoinPool**. (You will see how to create the computational portion of a task shortly.) However, with the advent of JDK 8, if **fork()** is not called while executing within a **ForkJoinPool**, then a common pool is automatically used. The **join()** method waits until the task on which it is called terminates. The result of the task is returned. Thus, through the use of **fork()** and **join()**, you can start one or more new tasks and then wait for them to finish.

Another important **ForkJoinTask** method is **invoke()**. It combines the fork and join operations into a single call because it begins a task and then waits for it to end. It is shown here:

```java
final V invoke()
```

The result of the invoking task is returned.

You can invoke more than one task at a time by using **invokeAll()**. Two of its forms are shown here:

```java
static void invokeAll(ForkJoinTask<? extends V> taskA, ForkJoinTask<? extends V> taskB)
static void invokeAll(ForkJoinTask<?> … taskList)
```

In the first case, `taskA` and `taskB` are executed. In the second case, all specified tasks are executed. In both cases, the calling thread waits until all of the specified tasks have terminated. Prior to JDK 8, the **invokeAll()** method could be executed only from within the computational portion of another **ForkJoinTask**, which is running within a **ForkJoinPool**. JDK 8’s inclusion of the common pool relaxed this requirement.

**RecursiveAction**

A subclass of **ForkJoinTask** is **RecursiveAction**. This class encapsulates a task that does not return a result. Typically, your code will extend **RecursiveAction** to create a task that has a `void` return type. **RecursiveAction** specifies four methods, but only one is usually of interest: the abstract method called **compute()**. When you extend **RecursiveAction** to create a concrete class, you will put the code that defines the task inside **compute()**. The **compute()** method represents the **computational** portion
of the task.

The **compute()** method is defined by **RecursiveAction** like this:

```java
protected abstract void compute()
```

Notice that **compute()** is **protected** and **abstract**. This means that it must be implemented by a subclass (unless that subclass is also abstract).

In general, **RecursiveAction** is used to implement a recursive, divide-and-conquer strategy for tasks that don’t return results. (See “The Divide-and-Conquer Strategy” later in this chapter.)

**RecursiveTask<V>**

Another subclass of **ForkJoinTask** is **RecursiveTask<V>**. This class encapsulates a task that returns a result. The result type is specified by **V**. Typically, your code will extend **RecursiveTask<V>** to create a task that returns a value. Like **RecursiveAction**, it too specifies four methods, but often only the abstract **compute()** method is used, which represents the computational portion of the task. When you extend **RecursiveTask<V>** to create a concrete class, put the code that represents the task inside **compute()**. This code must also return the result of the task.

The **compute()** method is defined by **RecursiveTask<V>** like this:

```java
protected abstract V compute()
```

Notice that **compute()** is **protected** and **abstract**. This means that it must be implemented by a subclass. When implemented, it must return the result of the task.

In general, **RecursiveTask** is used to implement a recursive, divide-and-conquer strategy for tasks that return results. (See “The Divide-and-Conquer Strategy” later in this chapter.)

**ForkJoinPool**

The execution of **ForkJoinTasks** takes place within a **ForkJoinPool**, which also manages the execution of the tasks. Therefore, in order to execute a **ForkJoinTask**, you must first have a **ForkJoinPool**. Beginning with JDK 8, there are two ways to acquire a **ForkJoinPool**. First, you can explicitly create one by using a **ForkJoinPool** constructor. Second, you can use what is referred to as the **common pool**. The common pool (which was added by JDK 8) is a static **ForkJoinPool** that is automatically available for your use. Each method is introduced here, beginning with manually constructing a pool.

**ForkJoinPool** defines several constructors. Here are two commonly used ones:
ForkJoinPool( )
ForkJoinPool(int pLevel)

The first creates a default pool that supports a level of parallelism equal to the number of processors available in the system. The second lets you specify the level of parallelism. Its value must be greater than zero and not more than the limits of the implementation. The level of parallelism determines the number of threads that can execute concurrently. As a result, the level of parallelism effectively determines the number of tasks that can be executed simultaneously. (Of course, the number of tasks that can execute simultaneously cannot exceed the number of processors.) It is important to understand that the level of parallelism does not, however, limit the number of tasks that can be managed by the pool. A ForkJoinPool can manage many more tasks than its level of parallelism. Also, the level of parallelism is only a target. It is not a guarantee.

After you have created an instance of ForkJoinPool, you can start a task in a number of different ways. The first task started is often thought of as the main task. Frequently, the main task begins subtasks that are also managed by the pool. One common way to begin a main task is to call invoke( ) on the ForkJoinPool. It is shown here:

\[
<T> T \text{ invoke(ForkJoinTask}<T> \ text{ task)}
\]

This method begins the task specified by task, and it returns the result of the task. This means that the calling code waits until invoke( ) returns.

To start a task without waiting for its completion, you can use execute( ). Here is one of its forms:

\[
\text{void execute(ForkJoinTask}<?> \ text{ task)}
\]

In this case, task is started, but the calling code does not wait for its completion. Rather, the calling code continues execution asynchronously.

Beginning with JDK 8, it is not necessary to explicitly construct a ForkJoinPool because a common pool is available for your use. In general, if you are not using a pool that you explicitly created, then the common pool will automatically be used. Although it won’t always be necessary, you can obtain a reference to the common pool by calling commonPool( ), which is defined by ForkJoinPool. It is shown here:

\[
\text{static ForkJoinPool commonPool( )}
\]
A reference to the common pool is returned. The common pool provides a default level of parallelism. It can be set by use of a system property. (See the API documentation for details.) Typically, the default common pool is a good choice for many applications. Of course, you can always construct your own pool.

There are two basic ways to start a task using the common pool. First, you can obtain a reference to the pool by calling `commonPool()` and then use that reference to call `invoke()` or `execute()`, as just described. Second, you can call `ForkJoinTask` methods such as `fork()` or `invoke()` on the task from outside its computational portion. In this case, the common pool will automatically be used. In other words, `fork()` and `invoke()` will start a task using the common pool if the task is not already running within a `ForkJoinPool`.

`ForkJoinPool` manages the execution of its threads using an approach called `work-stealing`. Each worker thread maintains a queue of tasks. If one worker thread’s queue is empty, it will take a task from another worker thread. This adds to overall efficiency and helps maintain a balanced load. (Because of demands on CPU time by other processes in the system, even two worker threads with identical tasks in their respective queues may not complete at the same time.)

One other point: `ForkJoinPool` uses daemon threads. A daemon thread is automatically terminated when all user threads have terminated. Thus, there is no need to explicitly shut down a `ForkJoinPool`. However, with the exception of the common pool, it is possible to do so by calling `shutdown()`. The `shutdown()` method has no effect on the common pool.

**The Divide-and-Conquer Strategy**

As a general rule, users of the Fork/Join Framework will employ a *divide-and-conquer* strategy that is based on recursion. This is why the two subclasses of `ForkJoinTask` are called `RecursiveAction` and `RecursiveTask`. It is anticipated that you will extend one of these classes when creating your own fork/join task.

The divide-and-conquer strategy is based on recursively dividing a task into smaller subtasks until the size of a subtask is small enough to be handled sequentially. For example, a task that applies a transform to each element in an array of $N$ integers can be broken down into two subtasks in which each transforms half the elements in the array. That is, one subtask transforms the elements 0 to $N/2$, and the other transforms the elements $N/2$ to $N$. In turn, each subtask can be reduced to another set of subtasks, each transforming half of the remaining elements. This process of dividing the array will continue until a threshold is reached in which a sequential solution is faster than creating another division.

The advantage of the divide-and-conquer strategy is that the processing can occur
in parallel. Therefore, instead of cycling through an entire array using a single thread, pieces of the array can be processed simultaneously. Of course, the divide-and-conquer approach works in many cases in which an array (or collection) is not present, but the most common uses involve some type of array, collection, or grouping of data.

One of the keys to best employing the divide-and-conquer strategy is correctly selecting the threshold at which sequential processing (rather than further division) is used. Typically, an optimal threshold is obtained through profiling the execution characteristics. However, very significant speed-ups will still occur even when a less-than-optimal threshold is used. It is, however, best to avoid overly large or overly small thresholds. At the time of this writing, the Java API documentation for `ForkJoinTask<T>` states that, as a rule-of-thumb, a task should perform somewhere between 100 and 10,000 computational steps.

It is also important to understand that the optimal threshold value is also affected by how much time the computation takes. If each computational step is fairly long, then smaller thresholds might be better. Conversely, if each computational step is quite short, then larger thresholds could yield better results. For applications that are to be run on a known system, with a known number of processors, you can use the number of processors to make informed decisions about the threshold value. However, for applications that will be running on a variety of systems, the capabilities of which are not known in advance, you can make no assumptions about the execution environment.

One other point: Although multiple processors may be available on a system, other tasks (and the operating system, itself) will be competing with your application for CPU time. Thus, it is important not to assume that your program will have unrestricted access to all CPUs. Furthermore, different runs of the same program may display different run time characteristics because of varying task loads.

**A Simple First Fork/Join Example**

At this point, a simple example that demonstrates the Fork/Join Framework and the divide-and-conquer strategy will be helpful. Following is a program that transforms the elements in an array of `double` into their square roots. It does so via a subclass of `RecursiveAction`. Notice that it creates its own `ForkJoinPool`. 
// A simple example of the basic divide-and-conquer strategy.
// In this case, RecursiveAction is used.
import java.util.concurrent.*/
import java.util.*;

// A ForkJoinTask (via RecursiveAction) that transforms
// the elements in an array of doubles into their square roots.
class SqrtTransform extends RecursiveAction {
    // The threshold value is arbitrarily set at 1,000 in this example.
    // In real-world code, its optimal value can be determined by
    // profiling and experimentation.
    final int seqThreshold = 1000;

    // Array to be accessed.
    double[] data;

    // Determines what part of data to process.
    int start, end;

    SqrtTransform(double[] vals, int s, int e ) {
        data = vals;
        start = s;
        end = e;
    }

    // This is the method in which parallel computation will occur.
    protected void compute() {

        // If number of elements is below the sequential threshold,
        // then process sequentially.
        if((end - start) < seqThreshold) {
            // Transform each element into its square root.
            for(int i = start; i < end; i++) {
                data[i] = Math.sqrt(data[i]);
            }
        } else {
            // Otherwise, continue to break the data into smaller pieces.

            // Find the midpoint.
            int middle = (start + end) / 2;
// Invoke new tasks, using the subdivided data.
invokeAll(new SqrtTransform(data, start, middle),
        new SqrtTransform(data, middle, end));
}
}

// Demonstrate parallel execution.
class ForkJoinDemo {
public static void main(String args[]) {
    // Create a task pool.
    ForkJoinPool fjp = new ForkJoinPool();

double[] nums = new double[100000];

    // Give nums some values.
    for(int i = 0; i < nums.length; i++)
        nums[i] = (double) i;

    System.out.println("A portion of the original sequence:");

    for(int i=0; i < 10; i++)
        System.out.print(nums[i] + " ");
    System.out.println("\n");

    SqrtTransform task = new SqrtTransform(nums, 0, nums.length);

    // Start the main ForkJoinTask.
    fjp.invoke(task);

    System.out.println("A portion of the transformed sequence" +
            " (to four decimal places):");
    for(int i=0; i < 10; i++)
        System.out.format("%.4f ", nums[i]);
    System.out.println();
}
}
A portion of the original sequence:
0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0

A portion of the transformed sequence (to four decimal places):
0.0000 1.0000 1.4142 1.7321 2.0000 2.2361 2.4495 2.6458 2.8284 3.0000

As you can see, the values of the array elements have been transformed into their square roots.

Let’s look closely at how this program works. First, notice that SqrtTransform is a class that extends RecursiveAction. As explained, RecursiveAction extends ForkJoinTask for tasks that do not return results. Next, notice the final variable seqThreshold. This is the value that determines when sequential processing will take place. This value is set (somewhat arbitrarily) to 1,000. Next, notice that a reference to the array to be processed is stored in data and that the fields start and end are used to indicate the boundaries of the elements to be accessed.

The main action of the program takes place in compute(). It begins by checking if the number of elements to be processed is below the sequential processing threshold. If it is, then those elements are processed (by computing their square root in this example). If the sequential processing threshold has not been reached, then two new tasks are started by calling invokeAll(). In this case, each subtask processes half the elements. As explained earlier, invokeAll() waits until both tasks return. After all of the recursive calls unwind, each element in the array will have been modified, with much of the action taking place in parallel (if multiple processors are available).

As mentioned, beginning with JDK 8, it is not necessary to explicitly construct a ForkJoinPool because a common pool is available for your use. Furthermore, using the common pool is a simple matter. For example, you can obtain a reference to the common pool by calling the static commonPool() method defined by ForkJoinPool. Therefore, the preceding program could be rewritten to use the common pool by replacing the call to the ForkJoinPool constructor with a call to commonPool(), as shown here:

ForkJoinPool fjp = ForkJoinPool.commonPool();

Alternatively, there is no need to explicitly obtain a reference to the common pool because calling the ForkJoinTask methods invoke() or fork() on a task that is not already part of a pool will cause it to execute within the common pool automatically. For example, in the preceding program, you can eliminate the fjp variable entirely and start the task using this line:

task.invoke();
As this discussion shows, the common pool can be easier to use than creating your own pool. Furthermore, in many cases, the common pool is the preferable approach.

**Understanding the Impact of the Level of Parallelism**

Before moving on, it is important to understand the impact that the level of parallelism has on the performance of a fork/join task and how the parallelism and the threshold interact. The program shown in this section lets you experiment with different degrees of parallelism and threshold values. Assuming that you are using a multicore computer, you can interactively observe the effect of these values.

In the preceding example, the default level of parallelism was used. However, you can specify the level of parallelism that you want. One way is to specify it when you create a `ForkJoinPool` using this constructor:

```java
ForkJoinPool(int pLevel)
```

Here, `pLevel` specifies the level of parallelism, which must be greater than zero and less than the implementation defined limit.

The following program creates a fork/join task that transforms an array of `doubles`. The transformation is arbitrary, but it is designed to consume several CPU cycles. This was done to ensure that the effects of changing the threshold or the level of parallelism would be more clearly displayed. To use the program, specify the threshold value and the level of parallelism on the command line. The program then runs the tasks. It also displays the amount of time it takes the tasks to run. To do this, it uses `System.nanoTime()`, which returns the value of the JVM’s high-resolution timer.
// A simple program that lets you experiment with the effects of changing the threshold and parallelism of a ForkJoinTask.
import java.util.concurrent.*;

// A ForkJoinTask (via RecursiveAction) that performs a transform on the elements of an array of doubles.
class Transform extends RecursiveAction {

    // Sequential threshold, which is set by the constructor.
    int seqThreshold;

    // Array to be accessed.
    double[] data;

    // Determines what part of data to process.
    int start, end;

    Transform(double[] vals, int s, int e, int t) {
        data = vals;
        start = s;
        end = e;
        seqThreshold = t;
    }

    // This is the method in which parallel computation will occur.
    protected void compute() {

        // If number of elements is below the sequential threshold, then process sequentially.
        if((end - start) < seqThreshold) {
            // The following code assigns an element at an even index the square root of its original value. An element at an odd index is assigned its cube root. This code is designed to simply consume CPU time so that the effects of concurrent execution are more readily observable.
            for(int i = start; i < end; i++) {
                if(((data[i] % 2) == 0)
                    data[i] = Math.sqrt(data[i]);
                else
                    data[i] = Math.cbrt(data[i]);
            }
        }
        else {
            // Otherwise, continue to break the data into smaller pieces.
        }
    }
}
// Find the midpoint.
int middle = (start + end) / 2;

// Invoke new tasks, using the subdivided data.
invokeAll(new Transform(data, start, middle, seqThreshold),
            new Transform(data, middle, end, seqThreshold));
}
}

// Demonstrate parallel execution.
class FJExperiment {

    public static void main(String args[]) {
        int pLevel;
        int threshold;

        if(args.length != 2) {
            System.out.println("Usage: FJExperiment parallelism threshold ");
            return;
        }
    }
}
To use the program, specify the level of parallelism followed by the threshold limit. You should try experimenting with different values for each, observing the results. Remember, to be effective, you must run the code on a computer with at least two processors. Also, understand that two different runs may (almost certainly will) produce different results because of the effect of other processes in the system consuming CPU time.

To give you an idea of the difference that parallelism makes, try this experiment. First, execute the program like this:

```java
pLevel = Integer.parseInt(args[0]);
threshold = Integer.parseInt(args[1]);

// These variables are used to time the task.
long beginT, endT;

// Create a task pool. Notice that the parallelism level is set.
ForkJoinPool fjp = new ForkJoinPool(pLevel);

double[] nums = new double[1000000];

for(int i = 0; i < nums.length; i++)
    nums[i] = (double) i;

Transform task = new Transform(nums, 0, nums.length, threshold);

// Starting timing.
beginT = System.nanoTime();

// Start the main ForkJoinTask.
fjp.invoke(task);

// End timing.
endT = System.nanoTime();

System.out.println("Level of parallelism: " + pLevel);
System.out.println("Sequential threshold: " + threshold);
System.out.println("Elapsed time: " + (endT - beginT) + " ns");
System.out.println();
```

```
This requests 1 level of parallelism (essentially sequential execution) with a threshold of 1,000. Here is a sample run produced on a dual-core computer:

Level of parallelism: 1
Sequential threshold: 1000
Elapsed time: 259677487 ns

Now, specify 2 levels of parallelism like this:

java FJExperiment 2 1000

Here is sample output from this run produced by the same dual-core computer:

Level of parallelism: 2
Sequential threshold: 1000
Elapsed time: 169254472 ns

As is evident, adding parallelism substantially decreases execution time, thus increasing the speed of the program. You should experiment with varying the threshold and parallelism on your own computer. The results may surprise you.

Here are two other methods that you might find useful when experimenting with the execution characteristics of a fork/join program. First, you can obtain the level of parallelism by calling `getParallelism()` , which is defined by `ForkJoinPool`. It is shown here:

```java
int getParallelism()
```

It returns the parallelism level currently in effect. Recall that for pools that you create, by default, this value will equal the number of available processors. (To obtain the parallelism level for the common pool, you can also use `getCommonPoolParallelism()` . Second, you can obtain the number of processors available in the system by calling `availableProcessors()` , which is defined by the `Runtime` class. It is shown here:

```java
int availableProcessors()
```

The value returned may change from one call to the next because of other system demands.

An Example that Uses RecursiveTask<V>

The two preceding examples are based on `RecursiveAction`, which means that they
concurrently execute tasks that do not return results. To create a task that returns a result, use **RecursiveTask.** In general, solutions are designed in the same manner as just shown. The key difference is that the `compute()` method returns a result. Thus, you must aggregate the results, so that when the first invocation finishes, it returns the overall result. Another difference is that you will typically start a subtask by calling `fork()` and `join()` explicitly (rather than implicitly by calling `invokeAll()`, for example).

The following program demonstrates **RecursiveTask.** It creates a task called `Sum` that returns the summation of the values in an array of `double. In this example, the array consists of 5,000 elements. However, every other value is negative. Thus, the first values in the array are 0, –1, 2, –3, 4, and so on. (Notice that this example creates its own pool. You might try changing it to use the common pool as an exercise.)
// A simple example that uses RecursiveTask.<V>.
import java.util.concurrent.*;

// A RecursiveTask that computes the summation of an array of doubles.
class Sum extends RecursiveTask<Double> {

    // The sequential threshold value.
    final int seqThreshold = 500;

    // Array to be accessed.
    double[] data;

    // Determines what part of data to process.
    int start, end;

    Sum(double[] vals, int s, int e) {
        data = vals;
        start = s;
        end = e;
    }

    // Find the summation of an array of doubles.
    protected Double compute() {
        double sum = 0;

        // If number of elements is below the sequential threshold,
        // then process sequentially.
        if((end - start) < seqThreshold) {
            // Sum the elements.
            for(int i = start; i < end; i++) sum += data[i];
        } else {
            // Otherwise, continue to break the data into smaller pieces.

            // Find the midpoint.
            int middle = (start + end) / 2;

            // Invoke new tasks, using the subdivided data.
            Sum subTaskA = new Sum(data, start, middle);
            Sum subTaskB = new Sum(data, middle, end);
// Start each subtask by forking.
subTaskA.fork();
subTaskB.fork();

// Wait for the subtasks to return, and aggregate the results.
sum = subTaskA.join() + subTaskB.join();

// Return the final sum.
return sum;

// Demonstrate parallel execution.
class RecurTaskDemo {
    public static void main(String args[]) {
        // Create a task pool.
        ForkJoinPool fjp = new ForkJoinPool();

        double[] nums = new double[5000];

        // Initialize nums with values that alternate between positive and negative.
        for(int i=0; i < nums.length; i++)
            nums[i] = (double) ((i%2) == 0) ? i : -i ;

        Sum task = new Sum(nums, 0, nums.length);

        // Start the ForkJoinTasks. Notice that, in this case, invoke() returns a result.
        double summation = fjp.invoke(task);

        System.out.println("Summation " + summation);
    }
}

Here's the output from the program:

Summation -2500.0

There are a couple of interesting items in this program. First, notice that the two subtasks are executed by calling fork(), as shown here:

subTaskA.fork();
subTaskB.fork();
In this case, \texttt{fork()} is used because it starts a task but does not wait for it to finish. (Thus, it asynchronously runs the task.) The result of each task is obtained by calling \texttt{join()}, as shown here:

\begin{verbatim}
sum = subTaskA.join() + subTaskB.join();
\end{verbatim}

This statement waits until each task ends. It then adds the results of each and assigns the total to \texttt{sum}. Thus, the summation of each subtask is added to the running total. Finally, \texttt{compute()} ends by returning \texttt{sum}, which will be the final total when the first invocation returns.

There are other ways to approach the handling of the asynchronous execution of the subtasks. For example, the following sequence uses \texttt{fork()} to start \texttt{subTaskA} and uses \texttt{invoke()} to start and wait for \texttt{subTaskB}:

\begin{verbatim}
subTaskA.fork();
sum = subTaskB.invoke() + subTaskA.join();
\end{verbatim}

Another alternative is to have \texttt{subTaskB} call \texttt{compute()} directly, as shown here:

\begin{verbatim}
subTaskA.fork();
sum = subTaskB.compute() + subTaskA.join();
\end{verbatim}

\section*{Executing a Task Asynchronously}

The preceding programs have called \texttt{invoke()} on a \texttt{ForkJoinPool} to initiate a task. This approach is commonly used when the calling thread must wait until the task has completed (which is often the case) because \texttt{invoke()} does not return until the task has terminated. However, you can start a task asynchronously. In this approach, the calling thread continues to execute. Thus, both the calling thread and the task execute simultaneously. To start a task asynchronously, use \texttt{execute()}, which is also defined by \texttt{ForkJoinPool}. It has the two forms shown here:

\begin{verbatim}
void execute(ForkJoinTask<?> task)
void execute(Runnable task)
\end{verbatim}

In both forms, \texttt{task} specifies the task to run. Notice that the second form lets you specify a \texttt{Runnable} rather than a \texttt{ForkJoinTask} task. Thus, it forms a bridge between Java’s traditional approach to multithreading and the new Fork/Join Framework. It is important to remember that the threads used by a \texttt{ForkJoinPool} are daemon. Thus, they will end when the main thread ends. As a result, you may need to keep the main thread alive until the tasks have finished.
Cancelling a Task
A task can be cancelled by calling `cancel()`, which is defined by `ForkJoinTask`. It has this general form:

```java
boolean cancel(boolean interruptOK)
```

It returns `true` if the task on which it was called is cancelled. It returns `false` if the task has ended or can’t be cancelled. At this time, the `interruptOK` parameter is not used by the default implementation. In general, `cancel()` is intended to be called from code outside the task because a task can easily cancel itself by returning.

You can determine if a task has been cancelled by calling `isCancelled()`, as shown here:

```java
final boolean isCancelled()
```

It returns `true` if the invoking task has been cancelled prior to completion and `false` otherwise.

Determining a Task’s Completion Status
In addition to `isCancelled()`, which was just described, `ForkJoinTask` includes two other methods that you can use to determine a task’s completion status. The first is `isCompletedNormally()`, which is shown here:

```java
final boolean isCompletedNormally()
```

It returns `true` if the invoking task completed normally, that is, if it did not throw an exception and it was not cancelled via a call to `cancel()`. It returns `false` otherwise.

The second is `isCompletedAbnormally()`, which is shown here:

```java
final boolean isCompletedAbnormally()
```

It returns `true` if the invoking task completed because it was cancelled or because it threw an exception. It returns `false` otherwise.

Restarting a Task
Normally, you cannot rerun a task. In other words, once a task completes, it cannot be restarted. However, you can reinitialize the state of the task (after it has completed) so it can be run again. This is done by calling `reinitialize()`, as shown here:
void reinitialize()

This method resets the state of the invoking task. However, any modification made to any persistent data that is operated upon by the task will not be undone. For example, if the task modifies an array, then those modifications are not undone by calling reinitialize().

Things to Explore
The preceding discussion presented the fundamentals of the Fork/Join Framework and described several commonly used methods. However, Fork/Join is a rich framework that includes additional capabilities that give you extended control over concurrency. Although it is far beyond the scope of this book to examine all of the issues and nuances surrounding parallel programming and the Fork/Join Framework, a sampling of the other features are mentioned here.

A Sampling of Other ForkJoinTask Features
In some cases, you will want to ensure that methods such as invokeAll() and fork() are called only from within a ForkJoinTask. This is usually a simple matter, but occasionally, you may have code that can be executed from either inside or outside a task. You can determine if your code is executing inside a task by calling inForkJoinPool().

You can convert a Runnable or Callable object into a ForkJoinTask by using the adapt() method defined by ForkJoinTask. It has three forms, one for converting a Callable, one for a Runnable that does not return a result, and one for a Runnable that does return a result. In the case of a Callable, the call() method is run. In the case of Runnable, the run() method is run.

You can obtain an approximate count of the number of tasks that are in the queue of the invoking thread by calling getQueuedTaskCount(). You can obtain an approximate count of how many tasks the invoking thread has in its queue that are in excess of the number of other threads in the pool that might “steal” them, by calling getSurplusQueuedTaskCount(). Remember, in the Fork/Join Framework, work-stealing is one way in which a high level of efficiency is obtained. Although this process is automatic, in some cases, the information may prove helpful in optimizing through-put.

ForkJoinTask defines the following variants of join() and invoke() that begin with the prefix quietly. They are shown here:
In essence, these methods are similar to their non-quiet counterparts except they don’t return values or throw exceptions.

You can attempt to “un-invoke” (in other words, unschedule) a task by calling `tryUnfork()`.

Several methods, such as `getForkJoinTaskTag()` and `setForkJoinTaskTag()`, support tags. Tags are short integer values that are linked with a task. They may be useful in specialized applications.

`ForkJoinTask` implements `Serializable`. Thus, it can be serialized. However, serialization is not used during execution.

### A Sampling of Other ForkJoinPool Features

One method that is quite useful when tuning fork/join applications is `ForkJoinPool`’s override of `toString()`. It displays a “user-friendly” synopsis of the state of the pool. To see it in action, use this sequence to start and then wait for the task in the `FJExperiment` class of the task experimenter program shown earlier:

```java
// Asynchronously start the main ForkJoinTask.
fjp.execute(task);

// Display the state of the pool while waiting.
while(!task.isDone()) {
    System.out.println(fjp);
}
```

When you run the program, you will see a series of messages on the screen that describe the state of the pool. Here is an example of one. Of course, your output may vary, based on the number of processors, threshold values, task load, and so on.

```
java.util.concurrent.ForkJoinPool@141d683[Running, parallelism = 2, size = 2, active = 0, running = 2, steals = 0, tasks = 0, submissions = 1]
```

You can determine if a pool is currently idle by calling `isQuiescent()`.

You can obtain the number of worker threads currently in the pool by calling `getPoolSize()`. You can obtain an approximate count of the active threads in the pool by calling `getActiveThreadCount()`.
To shut down a pool, call `shutdown()`. Currently active tasks will still be executed, but no new tasks can be started. To stop a pool immediately, call `shutdownNow()`. In this case, an attempt is made to cancel currently active tasks. (It is important to point out, however, that neither of these methods affects the common pool.) You can determine if a pool is shut down by calling `isShutdown()`. It returns `true` if the pool has been shut down and `false` otherwise. To determine if the pool has been shut down and all tasks have been completed, call `isTerminated()`.

Some Fork/Join Tips

Here are a few tips to help you avoid some of the more troublesome pitfalls associated with using the Fork/Join Framework. First, avoid using a sequential threshold that is too low. In general, erring on the high side is better than erring on the low side. If the threshold is too low, more time can be consumed generating and switching tasks than in processing the tasks. Second, usually it is best to use the default level of parallelism. If you specify a smaller number, it may significantly reduce the benefits of using the Fork/Join Framework.

In general, a `ForkJoinTask` should not use synchronized methods or synchronized blocks of code. Also, you will not normally want to have the `compute()` method use other types of synchronization, such as a semaphore. (The Phaser can, however, be used when appropriate because it is compatible with the fork/join mechanism.) Remember, the main idea behind a `ForkJoinTask` is the divide-and-conquer strategy. Such an approach does not normally lend itself to situations in which outside synchronization is needed. Also, avoid situations in which substantial blocking will occur through I/O. Therefore, in general, a `ForkJoinTask` will not perform I/O. Simply put, to best utilize the Fork/Join Framework, a task should perform a computation that can run without outside blocking or synchronization.

One last point: Except under unusual circumstances, do not make assumptions about the execution environment that your code will run in. This means you should not assume that some specific number of processors will be available, or that the execution characteristics of your program won’t be affected by other processes running at the same time.

The Concurrency Utilities Versus Java’s Traditional Approach

Given the power and flexibility found in the concurrency utilities, it is natural to ask the following question: Do they replace Java’s traditional approach to multithreading?
and synchronization? The answer is a resounding no! The original support for multithreading and the built-in synchronization features are still the mechanism that should be employed for many, many Java programs. For example, **synchronized**, `wait()` , and `notify()` offer elegant solutions to a wide range of problems. However, when extra control is needed, the concurrency utilities are available to handle the chore. Furthermore, the Fork/Join Framework offers a powerful way to integrate parallel programming techniques into your more sophisticated applications.
CHAPTER
29 The Stream API

Of the many new features recently added to Java, two of the most important are lambda expressions and the stream API. Lambda expressions were described in Chapter 15. The stream API is described here. As you will see, the stream API is designed with lambda expressions in mind. Moreover, the stream API provides some of the most significant demonstrations of the power that lambdas bring to Java.

Although its design compatibility with lambda expressions is impressive, the key aspect of the stream API is its ability to perform very sophisticated operations that search, filter, map, or otherwise manipulate data. For example, using the stream API, you can construct sequences of actions that resemble, in concept, the type of database queries for which you might use SQL. Furthermore, in many cases, such actions can be performed in parallel, thus providing a high level of efficiency, especially when large data sets are involved. Put simply, the stream API provides a powerful means of handling data in an efficient, yet easy to use way.

Before continuing, an important point needs to be made: The stream API uses some of Java’s most advanced features. To fully understand and utilize it requires a solid understanding of generics and lambda expressions. The basic concepts of parallel execution and a working knowledge of the Collections Framework are also needed. (See Chapters 14, 15, 19, and 28.)

Stream Basics

Let’s begin by defining the term stream as it applies to the stream API: a stream is a conduit for data. Thus, a stream represents a sequence of objects. A stream operates on a data source, such as an array or a collection. A stream, itself, never provides storage for the data. It simply moves data, possibly filtering, sorting, or otherwise operating on that data in the process. As a general rule, however, a stream operation by itself does not modify the data source. For example, sorting a stream does not change the order of the source. Rather, sorting a stream results in the creation of a new stream that produces the sorted result.

NOTE It is necessary to state that the term stream as used here differs from the use of stream when the I/O classes were described earlier in this book. Although an I/O stream can act conceptually much like one of the streams defined by
**java.util.stream**, they are not the same. Thus, throughout this chapter, when the term *stream* is used, it refers to objects based on one of the stream types described here.

**Stream Interfaces**

The stream API defines several stream interfaces, which are packaged in [java.util.stream](https://docs.oracle.com/javase/8/docs/api/java/util/stream/) and contained in the [java.base](https://docs.oracle.com/javase/8/docs/api/java/base/) module. At the foundation is **BaseStream**, which defines the basic functionality available in all streams. **BaseStream** is a generic interface declared like this:

```java
interface BaseStream<T, S extends BaseStream<T, S>>
```

Here, $T$ specifies the type of the elements in the stream, and $S$ specifies the type of stream that extends **BaseStream**. **BaseStream** extends the **AutoCloseable** interface; thus, a stream can be managed in a `try-with-resources` statement. In general, however, only those streams whose data source requires closing (such as those connected to a file) will need to be closed. In most cases, such as those in which the data source is a collection, there is no need to close the stream. The methods declared by **BaseStream** are shown in Table 29-1.
From **BaseStream** are derived several types of stream interfaces. The most general of these is **Stream**. It is declared as shown here:

```java
interface Stream<T>
```

Here, `T` specifies the type of the elements in the stream. Because it is generic, **Stream** is used for all reference types. In addition to the methods that it inherits from **BaseStream**, the **Stream** interface adds several of its own, a sampling of which is shown in **Table 29-2**.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void close( )</td>
<td>Closes the invoking stream, calling any registered close handlers. (As explained in the text, few streams need to be closed.)</td>
</tr>
<tr>
<td>boolean isParallel()</td>
<td>Returns <code>true</code> if the invoking stream is parallel. Returns <code>false</code> if the stream is sequential.</td>
</tr>
<tr>
<td>Iterator&lt;T&gt; iterator( )</td>
<td>Obtains an iterator to the stream and returns a reference to it. (Terminal operation.)</td>
</tr>
<tr>
<td>S onClose(Runnable handler)</td>
<td>Returns a new stream with the close handler specified by <code>handler</code>. This handler will be called when the stream is closed. (Intermediate operation.)</td>
</tr>
<tr>
<td>S parallel()</td>
<td>Returns a parallel stream based on the invoking stream. If the invoking stream is already parallel, then that stream is returned. (Intermediate operation.)</td>
</tr>
<tr>
<td>S sequential()</td>
<td>Returns a sequential stream based on the invoking stream. If the invoking stream is already sequential, then that stream is returned. (Intermediate operation.)</td>
</tr>
<tr>
<td>Splitter&lt;T&gt; splitter( )</td>
<td>Obtains a splitter to the stream and returns a reference to it. (Terminal operation.)</td>
</tr>
<tr>
<td>S unordered( )</td>
<td>Returns an unordered stream based on the invoking stream. If the invoking stream is already unordered, then that stream is returned. (Intermediate operation.)</td>
</tr>
</tbody>
</table>

**Table 29-1**  The Methods Declared by **BaseStream**
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>&lt;R, A&gt; R collect(Collectors super T, A, R&gt;</code></td>
<td>Collects elements into a container, which is changeable, and returns the container. This is called a mutable reduction operation. Here, R specifies the type of the resulting container and T specifies the element type of the invoking stream. A specifies the internal accumulated type. The <code>Collectors</code> specifies how the collection process works. (Terminal operation.)</td>
</tr>
<tr>
<td><code>long count()</code></td>
<td>Counts the number of elements in the stream and returns the result. (Terminal operation.)</td>
</tr>
<tr>
<td><code>Stream&lt;T&gt; filter(Predicate super T&gt;</code></td>
<td>Produces a stream that contains those elements from the invoking stream that satisfy the predicate specified by <code>Predicate</code>. (Intermediate operation.)</td>
</tr>
<tr>
<td><code>void forEach(Consumer super T)</code></td>
<td>For each element in the invoking stream, the code specified by <code>Consumer</code> is executed. (Terminal operation.)</td>
</tr>
<tr>
<td><code>&lt;R&gt; Stream&lt;R&gt; map(Function super T,</code></td>
<td>Applies <code>Function</code> to the elements from the invoking stream, yielding a new stream that contains those elements. (Intermediate operation.)</td>
</tr>
<tr>
<td><code>? extends R&gt;</code> <code>map</code></td>
<td></td>
</tr>
<tr>
<td><code>DoubleStream mapToDouble(ToDoubleFunction super T)</code></td>
<td>Applies <code>ToDoubleFunction</code> to the elements from the invoking stream, yielding a new <code>DoubleStream</code> that contains those elements. (Intermediate operation.)</td>
</tr>
<tr>
<td><code>IntStream mapToInt(ToIntFunction super T)</code></td>
<td>Applies <code>ToIntFunction</code> to the elements from the invoking stream, yielding a new <code>IntStream</code> that contains those elements. (Intermediate operation.)</td>
</tr>
<tr>
<td><code>LongStream mapToLong(ToLongFunction super T)</code></td>
<td>Applies <code>ToLongFunction</code> to the elements from the invoking stream, yielding a new <code>LongStream</code> that contains those elements. (Intermediate operation.)</td>
</tr>
<tr>
<td><code>Optional&lt;T&gt; max(Comparator super T)</code></td>
<td>Using the ordering specified by <code>Comparator</code>, finds and returns the maximum element in the invoking stream. (Terminal operation.)</td>
</tr>
</tbody>
</table>
In both tables, notice that many of the methods are notated as being either terminal or intermediate. The difference between the two is very important. A terminal operation consumes the stream. It is used to produce a result, such as finding the minimum value in the stream, or to execute some action, as is the case with the `forEach()` method. Once a stream has been consumed, it cannot be reused. Intermediate operations produce another stream. Thus, intermediate operations can be used to create a pipeline that performs a sequence of actions. One other point: intermediate operations do not take place immediately. Instead, the specified action is performed when a terminal operation is executed on the new stream created by an intermediate operation. This mechanism is referred to as lazy behavior, and the intermediate operations are referred to as lazy. The use of lazy behavior enables the stream API to perform more efficiently.

Another key aspect of streams is that some intermediate operations are stateless and some are stateful. In a stateless operation, each element is processed independently of the others. In a stateful operation, the processing of an element may depend on aspects of the other elements. For example, sorting is a stateful operation because an element’s order depends on the values of the other elements. Thus, the `sorted()` method is stateful. However, filtering elements based on a stateless predicate is stateless because each element is handled individually. Thus, `filter()` can (and should be) stateless. The difference between stateless and stateful operations is especially important when parallel processing of a stream is desired because a stateful operation may require more than one pass to complete.

Because Stream operates on object references, it can’t operate directly on primitive types. To handle primitive type streams, the stream API defines the

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optional&lt;T&gt; <code>min(Comparator&lt;? super T&gt; comp)</code></td>
<td>Using the ordering specified by <code>comp</code>, finds and returns the minimum element in the invoking stream. (Terminal operation.)</td>
</tr>
<tr>
<td>T <code>reduce(T identityVal, BinaryOperator&lt;T&gt; accumulator)</code></td>
<td>Returns a result based on the elements in the invoking stream. This is called a reduction operation. (Terminal operation.)</td>
</tr>
<tr>
<td><code>Stream&lt;T&gt; sorted()</code></td>
<td>Produces a new stream that contains the elements of the invoking stream sorted in natural order. (Intermediate operation.)</td>
</tr>
<tr>
<td><code>Object[] toArray()</code></td>
<td>Creates an array from the elements in the invoking stream. (Terminal operation.)</td>
</tr>
</tbody>
</table>

Table 29-2  A Sampling of Methods Declared by Stream
following interfaces:

DoubleStream
IntStream
LongStream

These streams all extend BaseStream and have capabilities similar to Stream except that they operate on primitive types rather than reference types. They also provide some convenience methods, such as boxed( ), that facilitate their use. Because streams of objects are the most common, Stream is the primary focus of this chapter, but the primitive type streams can be used in much the same way.

How to Obtain a Stream

You can obtain a stream in a number of ways. Perhaps the most common is when a stream is obtained for a collection. Beginning with JDK 8, the Collection interface was expanded to include two methods that obtain a stream from a collection. The first is stream( ), shown here:

    default Stream<E> stream( )

Its default implementation returns a sequential stream. The second method is parallelStream( ), shown next:

    default Stream<E> parallelStream( )

Its default implementation returns a parallel stream, if possible. (If a parallel stream can not be obtained, a sequential stream may be returned instead.) Parallel streams support parallel execution of stream operations. Because Collection is implemented by every collection, these methods can be used to obtain a stream from any collection class, such as ArrayList or HashSet.

A stream can also be obtained from an array by use of the static stream( ) method, which was added to the Arrays class. One of its forms is shown here:

    static <T> Stream<T> stream(T[ ] array)

This method returns a sequential stream to the elements in array. For example, given an array called addresses of type Address, the following obtains a stream to it:

    Stream<Address> addrStrm = Arrays.stream(addresses);
Several overloads of the `stream()` method are also defined, such as those that handle arrays of the primitive types. They return a stream of type `IntStream`, `DoubleStream`, or `LongStream`.

Streams can be obtained in a variety of other ways. For example, many stream operations return a new stream, and a stream to an I/O source can be obtained by calling `lines()` on a `BufferedReader`. However a stream is obtained, it can be used in the same way as any other stream.

**A Simple Stream Example**

Before going any further, let’s work through an example that uses streams. The following program creates an `ArrayList` called `myList` that holds a collection of integers (which are automatically boxed into the `Integer` reference type). Next, it obtains a stream that uses `myList` as a source. It then demonstrates various stream operations.

```java
// Demonstrate several stream operations.

import java.util.*;
import java.util.stream.*;
```
class StreamDemo {

    public static void main(String[] args) {

        // Create a list of Integer values.
        ArrayList<Integer> myList = new ArrayList<>();
        myList.add(7);
        myList.add(18);
        myList.add(10);
        myList.add(24);
        myList.add(17);
        myList.add(5);

        System.out.println("Original list: " + myList);

        // Obtain a Stream to the array list.
        Stream<Integer> myStream = myList.stream();

        // Obtain the minimum and maximum value by use of min(),
        // max(), isPresent(), and get().
        Optional<Integer> minVal = myStream.min(Integer::compare);
        if(minVal.isPresent()) System.out.println("Minimum value: " +
                minVal.get());

        // Must obtain a new stream because previous call to min()
        // is a terminal operation that consumed the stream.
        myStream = myList.stream();
        Optional<Integer> maxVal = myStream.max(Integer::compare);
        if(maxVal.isPresent()) System.out.println("Maximum value: " +
                maxVal.get());
    }
}
The output is shown here:

Original list: [7, 18, 10, 24, 17, 5]
Minimum value: 5
Maximum value: 24
Sorted stream: 5 7 10 17 18 24
Odd values: 5 7 17
Odd values greater than 5: 7 17

Let’s look closely at each stream operation. After creating an ArrayList, the program obtains a stream for the list by calling stream(), as shown here:

Stream<Integer> myStream = myList.stream();

As explained, the Collection interface defines the stream() method, which obtains a stream from the invoking collection. Because Collection is implemented by every collection class, stream() can be used to obtain a stream for any type of collection,
including the **ArrayList** used here. In this case, a reference to the stream is assigned to `myStream`.

Next, the program obtains the minimum value in the stream (which is, of course, also the minimum value in the data source) and displays it, as shown here:

```java
Optional<Integer> minVal = myStream.min(Comparator::compare);
if(minVal.isPresent()) System.out.println("Minimum value: " + minVal.get());
```

Recall from **Table 29-2** that `min()` is declared like this:

```
Optional<T> min(Comparator<? super T> comp)
```

First, notice that the type of `min()`’s parameter is a **Comparator**. This comparator is used to compare two elements in the stream. In the example, `min()` is passed a method reference to `Integer`’s `compare()` method, which is used to implement a **Comparator** capable of comparing two `Integers`. Next, notice that the return type of `min()` is **Optional**. The **Optional** class is described in Chapter 20, but briefly, here is how it works. **Optional** is a generic class packaged in `java.util` and declared like this:

```
class Optional<T>
```

Here, `T` specifies the element type. An **Optional** instance can either contain a value of type `T` or be empty. You can use `isPresent()` to determine if a value is present. Assuming that a value is available, it can be obtained by calling `get()`. In this example, the object returned will hold the minimum value of the stream as an `Integer` object.

One other point about the preceding line: `min()` is a terminal operation that consumes the stream. Thus, `myStream` cannot be used again after `min()` executes.

The next lines obtain and display the maximum value in the stream:

```java
myStream = myList.stream();
Optional<Integer> maxVal = myStream.max(Comparator::compare);
if(maxVal.isPresent()) System.out.println("Maximum value: " + maxVal.get());
```

First, `myStream` is once again assigned the stream returned by `myList.stream()`. As just explained, this is necessary because the previous call to `min()` consumed the previous stream. Thus, a new one is needed. Next, the `max()` method is called to obtain the maximum value. Like `min()`, `max()` returns an **Optional** object. Its value
is obtained by calling get().

The program then obtains a sorted stream through the use of this line:

```java
Stream<Integer> sortedStream = myList.stream().sorted();
```

Here, the `sorted()` method is called on the stream returned by `myList.stream()`. Because `sorted()` is an intermediate operation, its result is a new stream, and this is the stream assigned to `sortedStream`. The contents of the sorted stream are displayed by use of `forEach()`:

```java
sortedStream.forEach((n) -> System.out.print(n + " "));
```

Here, the `forEach()` method executes an operation on each element in the stream. In this case, it simply calls `System.out.print()` for each element in `sortedStream`. This is accomplished by use of a lambda expression. The `forEach()` method has this general form:

```java
void forEach(Consumer<? super T> action)
```

`Consumer` is a generic functional interface declared in `java.util.function`. Its abstract method is `accept()`, shown here:

```java
void accept(T objRef)
```

The lambda expression in the call to `forEach()` provides the implementation of `accept()`. The `forEach()` method is a terminal operation. Thus, after it completes, the stream has been consumed.

Next, a sorted stream is filtered by `filter()` so that it contains only odd values:

```java
Stream<Integer> oddVals =
    myList.stream().sorted().filter((n) -> (n % 2) == 1);
```

The `filter()` method filters a stream based on a predicate. It returns a new stream that contains only those elements that satisfy the predicate. It is shown here:

```java
Stream<T> filter(Predicate<? super T> pred)
```

`Predicate` is a generic functional interface defined in `java.util.function`. Its abstract method is `test()`, which is shown here:

```java
boolean test(T objRef)
```
It returns true if the object referred to by objRef satisfies the predicate, and false otherwise. The lambda expression passed to filter() implements this method. Because filter() is an intermediate operation, it returns a new stream that contains filtered values, which, in this case, are the odd numbers. These elements are then displayed via forEach() as before.

Because filter(), or any other intermediate operation, returns a new stream, it is possible to filter a filtered stream a second time. This is demonstrated by the following line, which produces a stream that contains only those odd values greater than 5:

```java
oddVals = myList.stream().filter((n) -> (n % 2) == 1)
        .filter((n) -> n > 5);
```

Notice that lambda expressions are passed to both filters.

### Reduction Operations

Consider the min() and max() methods in the preceding example program. Both are terminal operations that return a result based on the elements in the stream. In the language of the stream API, they represent *reduction operations* because each reduces a stream to a single value—in this case, the minimum and maximum. The stream API refers to these as *special case* reductions because they perform a specific function. In addition to min() and max(), other special case reductions are also available, such as count(), which counts the number of elements in a stream. However, the stream API generalizes this concept by providing the reduce() method. By using reduce(), you can return a value from a stream based on any arbitrary criteria. By definition, all reduction operations are terminal operations.

Stream defines three versions of reduce(). The two we will use first are shown here:

```java
Optional<T> reduce(BinaryOperator<T> accumulator)
T reduce(T identityVal, BinaryOperator<T> accumulator)
```

The first form returns an object of type Optional, which contains the result. The second form returns an object of type T (which is the element type of the stream). In both forms, accumulator is a function that operates on two values and produces a result. In the second form, identityVal is a value such that an accumulator operation involving identityVal and any element of the stream yields that element, unchanged. For example, if the operation is addition, then the identity value will be 0 because 0 + x is x. For multiplication, the value will be 1, because 1 * x is x.
**BinaryOperator** is a functional interface declared in *java.util.function* that extends the **BiFunction** functional interface. **BiFunction** defines this abstract method:

```java
R apply(T val, U val2)
```

Here, *R* specifies the result type, *T* is the type of the first operand, and *U* is the type of second operand. Thus, `apply()` applies a function to its two operands (`val` and `val2`) and returns the result. When **BinaryOperator** extends **BiFunction**, it specifies the same type for all the type parameters. Thus, as it relates to **BinaryOperator**, `apply()` looks like this:

```java
T apply(T val, T val2)
```

Furthermore, as it relates to `reduce()`, `val` will contain the previous result and `val2` will contain the next element. In its first invocation, `val` will contain either the identity value or the first element, depending on which version of `reduce()` is used.

It is important to understand that the accumulator operation must satisfy three constraints. It must be

- Stateless
- Non-interfering
- Associative

As explained earlier, **stateless** means that the operation does not rely on any state information. Thus, each element is processed independently. **Non-interfering** means that the data source is not modified by the operation. Finally, the operation must be **associative**. Here, the term **associative** is used in its normal, arithmetic sense, which means that, given an associative operator used in a sequence of operations, it does not matter which pair of operands are processed first. For example,

```
(10 * 2) * 7
```

yields the same result as

```
10 * (2 * 7)
```

Associativity is of particular importance to the use of reduction operations on parallel streams, discussed in the next section.

The following program demonstrates the versions of `reduce()` just described:
As the output here shows, both uses of `reduce()` produce the same result:

```
Product as Optional: 2570400
Product as int: 2570400
```

In the program, the first version of `reduce()` uses the lambda expression to produce a product of two values. In this case, because the stream contains `Integer` values, the `Integer` objects are automatically unboxed for the multiplication and reboxed to return the result. The two values represent the current value of the running result and the next element in the stream. The final result is returned in an object of type `Optional`. The value is obtained by calling `get()` on the returned object.

In the second version, the identity value is explicitly specified, which for
multiplication is 1. Notice that the result is returned as an object of the element type, which is `Integer` in this case.

Although simple reduction operations such as multiplication are useful for examples, reductions are not limited in this regard. For example, assuming the preceding program, the following obtains the product of only the even values:

```java
int evenProduct = myList.stream().reduce(1, (a, b) -> {
    if(b%2 == 0) return a*b; else return a;
});
```

Pay special attention to the lambda expression. If \( b \) is even, then \( a \times b \) is returned. Otherwise, \( a \) is returned. This works because \( a \) holds the current result and \( b \) holds the next element, as explained earlier.

### Using Parallel Streams

Before exploring any more of the stream API, it will be helpful to discuss parallel streams. As has been pointed out previously in this book, the parallel execution of code via multicore processors can result in a substantial increase in performance. Because of this, parallel programming has become an important part of the modern programmer’s job. However, parallel programming can be complex and error-prone. One of the benefits that the stream library offers is the ability to easily—and reliably—parallel process certain operations.

Parallel processing of a stream is quite simple to request: just use a parallel stream. As mentioned earlier, one way to obtain a parallel stream is to use the `parallelStream()` method defined by `Collection`. Another way to obtain a parallel stream is to call the `parallel()` method on a sequential stream. The `parallel()` method is defined by `BaseStream`, as shown here:

```java
S parallel()
```

It returns a parallel stream based on the sequential stream that invokes it. (If it is called on a stream that is already parallel, then the invoking stream is returned.) Understand, of course, that even with a parallel stream, parallelism will be achieved only if the environment supports it.

Once a parallel stream has been obtained, operations on the stream can occur in parallel, assuming that parallelism is supported by the environment. For example, the first `reduce()` operation in the preceding program can be parallelized by substituting `parallelStream()` for the call to `stream()`:
Optional<Integer> productObj = myList.parallelStream().reduce((a, b) -> a*b);

The results will be the same, but the multiplications can occur in different threads.

As a general rule, any operation applied to a parallel stream must be stateless. It should also be non-interfering and associative. This ensures that the results obtained by executing operations on a parallel stream are the same as those obtained from executing the same operations on a sequential stream.

When using parallel streams, you might find the following version of \texttt{reduce()} especially helpful. It gives you a way to specify how partial results are combined:

\begin{verbatim}
<U> U reduce(U identityVal, BiFunction<U, ? super T, U> accumulator
    BinaryOperator<U> combiner)
\end{verbatim}

In this version, \texttt{combiner} defines the function that combines two values that have been produced by the \texttt{accumulator} function. Assuming the preceding program, the following statement computes the product of the elements in \texttt{myList} by use of a parallel stream:

\begin{verbatim}
int parallelProduct = myList.parallelStream().reduce(1, (a, b) -> a*b,
    (a, b) -> a*b);
\end{verbatim}

As you can see, in this example, both the accumulator and combiner perform the same function. However, there are cases in which the actions of the accumulator must differ from those of the combiner. For example, consider the following program. Here, \texttt{myList} contains a list of \texttt{double} values. It then uses the combiner version of \texttt{reduce()} to compute the product of the \texttt{square roots} of each element in the list.

\begin{verbatim}
int parallelProduct = myList.parallelStream().reduce(1, (a, b) -> a*b,
    (a, b) -> a*b);
\end{verbatim}
// Demonstrate the use of a combiner with reduce()

import java.util.*;  
import java.util.stream.*;

class StreamDemo3 {

    public static void main(String[] args) {

        // This is now a list of double values.
        ArrayList<Double> myList = new ArrayList<>();

        myList.add(7.0);
        myList.add(18.0);
        myList.add(10.0);
        myList.add(24.0);
        myList.add(17.0);
        myList.add(5.0);

        double productOfSqrRoots = myList.parallelStream().reduce( 
            1.0, 
            (a,b) -> a * Math.sqrt(b), 
            (a,b) -> a * b 
        );

        System.out.println("Product of square roots: " + productOfSqrRoots);
    }
}

Notice that the accumulator function multiplies the square roots of two elements, but the combiner multiplies the partial results. Thus, the two functions differ. Moreover, for this computation to work correctly, they must differ. For example, if you tried to obtain the product of the square roots of the elements by using the following statement, an error would result:

    // This won't work.
    double productOfSqrRoots2 = myList.parallelStream().reduce( 
        1.0, 
        (a,b) -> a * Math.sqrt(b));

In this version of reduce(), the accumulator and the combiner function are one and the same. This results in an error because when two partial results are combined, their square roots are multiplied together rather than the partial results, themselves.
As a point of interest, if the stream in the preceding call to `reduce()` had been changed to a sequential stream, then the operation would yield the correct answer because there would have been no need to combine two partial results. The problem occurs when a parallel stream is used.

You can switch a parallel stream to sequential by calling the `sequential()` method, which is specified by `BaseStream`. It is shown here:

```
S sequential()
```

In general, a stream can be switched between parallel and sequential on an as-needed basis.

There is one other aspect of a stream to keep in mind when using parallel execution: the order of the elements. Streams can be either ordered or unordered. In general, if the data source is ordered, then the stream will also be ordered. However, when using a parallel stream, a performance boost can sometimes be obtained by allowing a stream to be unordered. When a parallel stream is unordered, each partition of the stream can be operated on independently, without having to coordinate with the others. In cases in which the order of the operations does not matter, it is possible to specify unordered behavior by calling the `unordered()` method, shown here:

```
S unordered()
```

One other point: the `forEach()` method may not preserve the ordering of a parallel stream. If you want to perform an operation on each element in a parallel stream while preserving the order, consider using `forEachOrdered()`. It is used just like `forEach()`.

**Mapping**

Often it is useful to map the elements of one stream to another. For example, a stream that contains a database of name, telephone, and e-mail address information might map only the name and e-mail address portions to another stream. As another example, you might want to apply some transformation to the elements in a stream. To do this, you could map the transformed elements to a new stream. Because mapping operations are quite common, the stream API provides built-in support for them. The most general mapping method is `map()`. It is shown here:

```
<R> Stream<R> map(Function<? super T, ? extends R> mapFunc)
```
Here, \( R \) specifies the type of elements of the new stream; \( T \) is the type of elements of the invoking stream; and \( \text{mapFunc} \) is an instance of \textbf{Function}, which does the mapping. The map function must be stateless and non-interfering. Since a new stream is returned, \texttt{map()} is an intermediate method.

\textbf{Function} is a functional interface declared in \texttt{java.util.function}. It is declared as shown here:

\[
\text{Function}\langle T, R \rangle
\]

As it relates to \texttt{map()}, \( T \) is the element type and \( R \) is the result of the mapping. \textbf{Function} has the abstract method shown here:

\[
\text{R apply(T val)}
\]

Here, \( \text{val} \) is a reference to the object being mapped. The mapped result is returned.

The following is a simple example of \texttt{map()}. It provides a variation on the previous example program. As before, the program computes the product of the square roots of the values in an \texttt{ArrayList}. In this version, however, the square roots of the elements are first mapped to a new stream. Then, \texttt{reduce()} is employed to compute the product.

```java
// Map one stream to another.

import java.util.*;
import java.util.stream.*;

class StreamDemo4 {

    public static void main(String[] args) {

        // A list of double values.
        ArrayList<Double> myList = new ArrayList<>( );

        myList.add(7.0);
        myList.add(18.0);
        myList.add(10.0);
        myList.add(24.0);
        myList.add(17.0);
        myList.add(5.0);
```
// Map the square root of the elements in myList to a new stream.
Stream<Double> sqrtRootStrm = myList.stream().map((a) -> Math.sqrt(a));

// Find the product of the square roots.
double productOfSqrRoots = sqrtRootStrm.reduce(1.0, (a,b) -> a*b);

System.out.println("Product of square roots is " + productOfSqrRoots);
}

The output is the same as before. The difference between this version and the previous is simply that the transformation (i.e., the computation of the square roots) occurs during mapping, rather than during the reduction. Because of this, it is possible to use the two-parameter form of reduce() to compute the product because it is no longer necessary to provide a separate combiner function.

Here is an example that uses map() to create a new stream that contains only selected fields from the original stream. In this case, the original stream contains objects of type NamePhoneEmail, which contains names, phone numbers, and e-mail addresses. The program then maps only the names and phone numbers to a new stream of NamePhone objects. The e-mail addresses are discarded.
// Use map() to create a new stream that contains only
// selected aspects of the original stream.

import java.util.*;
import java.util.stream.*;

class NamePhoneEmail {
    String name;
    String phonenum;
    String email;

    NamePhoneEmail(String n, String p, String e) {
        name = n;
        phonenum = p;
        email = e;
    }
}

class NamePhone {
    String name;
    String phonenum;

    NamePhone(String n, String p) {
        name = n;
        phonenum = p;
    }
}
class StreamDemo5 {

    public static void main(String[] args) {

        // A list of names, phone numbers, and e-mail addresses.
        ArrayList<NamePhoneEmail> myList = new ArrayList<>();

        myList.add(new NamePhoneEmail("Larry", "555-5555",
                                   "Larry@HerbSchildt.com");
        myList.add(new NamePhoneEmail("James", "555-4444",
                                   "James@HerbSchildt.com");
        myList.add(new NamePhoneEmail("Mary", "555-3333",
                                   "Mary@HerbSchildt.com");

        System.out.println("Original values in myList: ");
        myList.stream().forEach( (a) -> {  
            System.out.println(a.name + " " + a.phonenum + " " + a.email);
        });
        System.out.println();

        // Map just the names and phone numbers to a new stream.
        Stream<NamePhone> nameAndPhone = myList.stream().map(  
            (a) -> new NamePhone(a.name, a.phonenum)
        );

        System.out.println("List of names and phone numbers: ");
        nameAndPhone.forEach( (a) -> {  
            System.out.println(a.name + " " + a.phonenum);
        });
    }
}

The output, shown here, verifies the mapping:

Original values in myList:
Larry 555-5555 Larry@HerbSchildt.com
James 555-4444 James@HerbSchildt.com
Mary 555-3333 Mary@HerbSchildt.com

List of names and phone numbers:
Larry 555-5555
James 555-4444
Mary 555-3333
Because you can pipeline more than one intermediate operation together, you can easily create very powerful actions. For example, the following statement uses **filter( )** and then **map( )** to produce a new stream that contains only the name and phone number of the elements with the name "James":

```java
Stream<NamePhone> nameAndPhone = myList.stream()
    .filter((a) -> a.name.equals("James"))
    .map((a) -> new NamePhone(a.name, a.phonenum));
```

This type of filter operation is very common when creating database-style queries. As you gain experience with the stream API, you will find that such chains of operations can be used to create very sophisticated queries, merges, and selections on a data stream.

In addition to the version just described, three other versions of **map( )** are provided. They return a primitive stream, as shown here:

```java
IntStream mapToInt(ToIntFunction<? super T> mapFunc)
LongStream mapToLong(ToLongFunction<? super T> mapFunc)
DoubleStream mapToDouble(ToDoubleFunction<? super T> mapFunc)
```

Each *mapFunc* must implement the abstract method defined by the specified interface, returning a value of the indicated type. For example, **ToDoubleFunction** specifies the `applyAsDouble(T val)` method, which must return the value of its parameter as a `double`.

Here is an example that uses a primitive stream. It first creates an `ArrayList` of `Double` values. It then uses `stream( )` followed by `mapToInt( )` to create an `IntStream` that contains the ceiling of each value.
// Map a Stream to an IntStream.

import java.util.*;
import java.util.stream.*;

class StreamDemo6 {
    
    public static void main(String[] args) {
        
        // A list of double values.
        ArrayList<Double> myList = new ArrayList<>();
        myList.add(1.1);
        myList.add(3.6);
        myList.add(9.2);
        myList.add(4.7);
        myList.add(12.1);
        myList.add(5.0);

        System.out.print("Original values in myList: ");
        myList.stream().forEach( (a) -> {
            System.out.print(a + " ");
        });
        System.out.println();

        // Map the ceiling of the elements in myList to an IntStream.
        IntStream cStrm = myList.stream().mapToInt((a) -> (int) Math.ceil(a));

        System.out.print("The ceilings of the values in myList: ");
        cStrm.forEach( (a) -> {
            System.out.print(a + " ");
        });
    }
}

The output is shown here:

Original values in myList: 1.1 3.6 9.2 4.7 12.1 5.0
The ceilings of the values in myList: 2 4 10 5 13 5

The stream produced by mapToInt() contains the ceiling values of the original elements in myList.
Before leaving the topic of mapping, it is necessary to point out that the stream API also provides methods that support flat maps. These are `flatMap()`, `flatMapToInt()`, `flatMapToLong()`, and `flatMapToDouble()`. The flat map methods are designed to handle situations in which each element in the original stream is mapped to more than one element in the resulting stream.

**Collecting**

As the preceding examples have shown, it is possible (indeed, common) to obtain a stream from a collection. Sometimes it is desirable to obtain the opposite: to obtain a collection from a stream. To perform such an action, the stream API provides the `collect()` method. It has two forms. The one we will use first is shown here:

```
<R, A> R collect(Collector<? super T, A, R> collectorFunc)
```

Here, `R` specifies the type of the result, and `T` specifies the element type of the invoking stream. The internal accumulated type is specified by `A`. The `collectorFunc` specifies how the collection process works. The `collect()` method is a terminal operation.

The `Collector` interface is declared in `java.util.stream`, as shown here:

```
interface Collector<T, A, R>
```

`T`, `A`, and `R` have the same meanings as just described. `Collector` specifies several methods, but for the purposes of this chapter, we won’t need to implement them. Instead, we will use two of the predefined collectors that are provided by the `Collectors` class, which is packaged in `java.util.stream`.

The `Collectors` class defines a number of static collector methods that you can use as-is. The two we will use are `toList()` and `toSet()`, shown here:

```
static <T> Collector<T, ?, List<T>> toList()
static <T> Collector<T, ?, Set<T>> toSet()
```

The `toList()` method returns a collector that can be used to collect elements into a `List`. The `toSet()` method returns a collector that can be used to collect elements into a `Set`. For example, to collect elements into a `List`, you can call `collect()` like this:

```
collect(Collectors.toList())
```

The following program puts the preceding discussion into action. It reworks the example in the previous section so that it collects the names and phone numbers into
a List and a Set.
// Use collect() to create a List and a Set from a stream.

import java.util.*;
import java.util.stream.*;

class NamePhoneEmail {
    String name;
    String phonenum;
    String email;

    NamePhoneEmail(String n, String p, String e) {
        name = n;
        phonenum = p;
        email = e;
    }
}

class NamePhone {
    String name;
    String phonenum;

    NamePhone(String n, String p) {
        name = n;
        phonenum = p;
    }
}

class StreamDemo7 {

    public static void main(String[] args) {

        // A list of names, phone numbers, and e-mail addresses.
        ArrayList<NamePhoneEmail> myList = new ArrayList<>();

        myList.add(new NamePhoneEmail("Larry", "555-5555", "Larry@HerbSchildt.com");
        myList.add(new NamePhoneEmail("James", "555-4444", "James@HerbSchildt.com");
        myList.add(new NamePhoneEmail("Mary", "555-3333", "Mary@HerbSchildt.com");

        // Map just the names and phone numbers to a new stream.
        Stream<NamePhone> nameAndPhone = myList.stream().map(
            (a) -> new NamePhone(a.name, a.phonenum)
        );

        // Use collect to create a List of the names and phone numbers.
        List<NamePhone> npList = nameAndPhone.collect(Collectors.toList());
    }
}
In the program, the following line collects the name and phone numbers into a List by using toList():

```java
List<NamePhone> npList = nameAndPhone.collect(Collectors.toList());
```

After this line executes, the collection referred to by npList can be used like any other List collection. For example, it can be cycled through by using a for-each for loop, as shown in the next line:

```java
for (NamePhone e : npList)
    System.out.println(e.name + ":
```
The creation of a `Set` via `collect(Collectors.toSet())` works in the same way. The ability to move data from a collection to a stream, and then back to a collection again is a very powerful attribute of the stream API. It gives you the ability to operate on a collection through a stream, but then repackage it as a collection. Furthermore, the stream operations can, if appropriate, occur in parallel.

The version of `collect()` used by the previous example is quite convenient, and often the one you want, but there is a second version that gives you more control over the collection process. It is shown here:

```java
<R> R collect(Supplier<R> target, BiConsumer<R, ? super T> accumulator, BiConsumer <R, R> combiner)
```

Here, `target` specifies how the object that holds the result is created. For example, to use a `LinkedList` as the result collection, you would specify its constructor. The `accumulator` function adds an element to the result and `combiner` combines two partial results. Thus, these functions work similarly to the way they do in `reduce()`. For both, they must be stateless and non-interfering. They must also be associative.

Note that the `target` parameter is of type `Supplier`. It is a functional interface declared in `java.util.function`. It specifies only the `get()` method, which has no parameters and, in this case, returns an object of type `R`. Thus, as it relates to `collect()`, `get()` returns a reference to a mutable storage object, such as a collection.

Note also that the types of `accumulator` and `combiner` are `BiConsumer`. This is a functional interface defined in `java.util.function`. It specifies the abstract method `accept()` that is shown here:

```java
void accept(T obj, U obj2)
```

This method performs some type of operation on `obj` and `obj2`. As it relates to `accumulator`, `obj` specifies the target collection, and `obj2` specifies the element to add to that collection. As it relates to `combiner`, `obj` and `obj2` specify two collections that will be combined.

Using the version of `collect()` just described, you could use a `LinkedList` as the target in the preceding program, as shown here:

```java
LinkedList<NamePhone> npList = nameAndPhone.collect(
    () -> new LinkedList<>(),
    (list, element) -> list.add(element),
    (listA, listB) -> listA.addAll(listB));
```

Notice that the first argument to `collect()` is a lambda expression that returns a new `LinkedList`. The second argument uses the standard collection method `add()` to add
an element to the list. The third element uses `addAll()` to combine two linked lists. As a point of interest, you can use any method defined by `LinkedList` to add an element to the list. For example, you could use `addFirst()` to add elements to the start of the list, as shown here:

(list, element) -> list.addFirst(element)

As you may have guessed, it is not always necessary to specify a lambda expression for the arguments to `collect()`. Often, method and/or constructor references will suffice. For example, again assuming the preceding program, this statement creates a `HashSet` that contains all of the elements in the `nameAndPhone` stream:

```java
HashSet<NamePhone> npSet = nameAndPhone.collect(HashSet::new,
                                                 HashSet::add,
                                                 HashSet::addAll);
```

Notice that the first argument specifies the `HashSet` constructor reference. The second and third specify method references to `HashSet`’s `add()` and `addAll()` methods.

One last point: In the language of the stream API, the `collect()` method performs what is called a *mutable reduction*. This is because the result of the reduction is a mutable (i.e., changeable) storage object, such as a collection.

**Iterators and Streams**

Although a stream is not a data storage object, you can still use an iterator to cycle through its elements in much the same way as you would use an iterator to cycle through the elements of a collection. The stream API supports two types of iterators. The first is the traditional `Iterator`. The second is `Spliterator`, which was added by JDK 8. It provides significant advantages in certain situations when used with parallel streams.

**Use an Iterator with a Stream**

As just mentioned, you can use an iterator with a stream in just the same way that you do with a collection. Iterators are discussed in Chapter 19, but a brief review will be useful here. Iterators are objects that implement the `Iterator` interface declared in `java.util`. Its two key methods are `hasNext()` and `next()`. If there is another element to iterate, `hasNext()` returns `true`, and `false` otherwise. The `next()` method returns the next element in the iteration.
NOTE There are additional iterator types that handle the primitive streams:
   PrimitiveIterator, PrimitiveIterator.OfDouble, PrimitiveIterator.OfLong,
   and PrimitiveIterator.OfInt. These iterators all extend the Iterator interface
   and work in the same general way as those based directly on Iterator.

To obtain an iterator to a stream, call iterator() on the stream. The version used
by Stream is shown here.
   Iterator<T> iterator()

Here, T specifies the element type. (The primitive streams return iterators of the
appropriate primitive type.)

The following program shows how to iterate through the elements of a stream. In
this case, the strings in an ArrayList are iterated, but the process is the same for any
type of stream.

// Use an iterator with a stream.

import java.util.*;
import java.util.stream.*;

class StreamDemo8 {

   public static void main(String[] args) {

      // Create a list of Strings.
      ArrayList<String> myList = new ArrayList<>();
      myList.add("Alpha");
      myList.add("Beta");
      myList.add("Gamma");
      myList.add("Delta");
      myList.add("Phi");
      myList.add("Omega");

      // Obtain a Stream to the array list.
      Stream<String> myStream = myList.stream();
// Obtain an iterator to the stream.
Iterator<String> itr = myStream.iterator();

// Iterate the elements in the stream.
while(itr.hasNext())
    System.out.println(itr.next());
}
}

The output is shown here:

Alpha
Beta
Gamma
Delta
Phi
Omega

**Use Spliterator**

Spliterator offers an alternative to Iterator, especially when parallel processing is involved. In general, Spliterator is more sophisticated than Iterator, and a discussion of Spliterator is found in Chapter 19. However, it will be useful to review its key features here. Spliterator defines several methods, but we only need to use three. The first is `tryAdvance()`. It performs an action on the next element and then advances the iterator. It is shown here:

```
boolean tryAdvance(Consumer<? super T> action)
```

Here, action specifies the action that is executed on the next element in the iteration. tryAdvance() returns true if there is a next element. It returns false if no elements remain. As discussed earlier in this chapter, Consumer declares one method called accept() that receives an element of type T as an argument and returns void.

Because tryAdvance() returns false when there are no more elements to process, it makes the iteration loop construct very simple, for example:

```
while(splItr.tryAdvance( // perform action here ));
```

As long as tryAdvance() returns true, the action is applied to the next element. When tryAdvance() returns false, the iteration is complete. Notice how tryAdvance() consolidates the purposes of hasNext() and next() provided by Iterator into a single method. This improves the efficiency of the iteration process.
The following version of the preceding program substitutes a **Spliterator** for the **Iterator**:

```java
// Use a Spliterator.
import java.util.*;
import java.util.stream.*;

class StreamDemo9 {

    public static void main(String[] args) {

        // Create a list of Strings.
        ArrayList<String> myList = new ArrayList<>();
        myList.add("Alpha");
        myList.add("Beta");
        myList.add("Gamma");
        myList.add("Delta");
        myList.add("Phi");
        myList.add("Omega");

        // Obtain a Stream to the array list.
        Stream<String> myListStream = myList.stream();

        // Obtain a Spliterator.
        Spliterator<String> splitIter = myListStream.spliterator();

        // Iterate the elements of the stream.
        while(splitIter.tryAdvance((n) -> System.out.println(n)));
    }
}
```

The output is the same as before.

In some cases, you might want to perform some action on each element collectively, rather than one at a time. To handle this type of situation, **Spliterator** provides the `forEachRemaining( )` method, shown here:

```java
    default void forEachRemaining(Consumer<? super T> action)
```

This method applies `action` to each unprocessed element and then returns. For example, assuming the preceding program, the following displays the strings remaining in the stream:
Notice how this method eliminates the need to provide a loop to cycle through the elements one at a time. This is another advantage of `Spliterator`.

One other `Spliterator` method of particular interest is `trySplit()`. It splits the elements being iterated in two, returning a new `Spliterator` to one of the partitions. The other partition remains accessible by the original `Spliterator`. It is shown here:

```
Spliterator<T> trySplit()
```

If it is not possible to split the invoking `Spliterator`, `null` is returned. Otherwise, a reference to the partition is returned. For example, here is another version of the preceding program that demonstrates `trySplit()`:

```java
splitItr.forEachRemaining(n -> System.out.println(n));
```
// Demonstrate trySplit().

import java.util.*;
import java.util.stream.*;

class StreamDemo10 {

    public static void main(String[] args) {

        // Create a list of Strings.
        ArrayList<String> myList = new ArrayList<>();
        myList.add("Alpha");
        myList.add("Beta");
        myList.add("Gamma");
        myList.add("Delta");
        myList.add("Phi");
        myList.add("Omega");

        // Obtain a Stream to the array list.
        Stream<String> myStream = myList.stream();

        // Obtain a Spliterator.
        Spliterator<String> splitItr = myStream.spliterator();

        // Now, split the first iterator.
        Spliterator<String> splitItr2 = splitItr.trySplit();

        // If splitItr could be split, use splitItr2 first.
        if(splitItr2 != null) {
            System.out.println("Output from splitItr2: ");
            splitItr2.forEachRemaining((n) -> System.out.println(n));
        }

        // Now, use the splitItr.
        System.out.println("\nOutput from splitItr: ");
        splitItr.forEachRemaining((n) -> System.out.println(n));
    }
}

The output is shown here:
Although splitting the **Spliterator** in this simple illustration is of no practical value, splitting can be of *great value* when parallel processing over large data sets. However, in many cases, it is better to use one of the other **Stream** methods in conjunction with a parallel stream, rather than manually handling these details with **Spliterator**. **Spliterator** is primarily for the cases in which none of the predefined methods seems appropriate.

### More to Explore in the Stream API

This chapter has discussed several key aspects of the stream API and introduced the techniques required to use them, but the stream API has much more to offer. To begin, here are a few of the other methods provided by **Stream** that you will find helpful:

- To determine if one or more elements in a stream satisfy a specified predicate, use `allMatch( )`, `anyMatch( )`, or `noneMatch( )`.
- To obtain the number of elements in the stream, call `count( )`.
- To obtain a stream that contains only unique elements, use `distinct( )`.
- To create a stream that contains a specified set of elements, use `of( )`.

One last point: the stream API is a powerful addition to Java. You will want to explore all of the capabilities that `java.util.stream` has to offer.
CHAPTER
30 Regular Expressions and Other Packages

When Java was originally released, it included a set of eight packages, called the core API. Each subsequent release added to the API. Today, the Java API contains a very large number of packages. Many of the packages support areas of specialization that are beyond the scope of this book. However, several packages warrant an examination here. Four are java.util.regex, java.lang.reflect, java.rmi, and java.text. They support regular expression processing, reflection, Remote Method Invocation (RMI), and text formatting, respectively. The chapter ends by introducing the date and time API in java.time and its subpackages.

The regular expression package lets you perform sophisticated pattern matching operations. This chapter provides an introduction to this package along with extensive examples. Reflection is the ability of software to analyze itself. It is an essential part of the Java Beans technology that is covered in Chapter 37. Remote Method Invocation (RMI) allows you to build Java applications that are distributed among several machines. This chapter provides a simple client/server example that uses RMI. The text formatting capabilities of java.text have many uses. The one examined here formats date and time strings. The date and time API supplies an up-to-date approach to handling date and time.

Regular Expression Processing

The java.util.regex package supports regular expression processing. Beginning with JDK 9, java.util.regex is in the java.base module. As the term is used here, a regular expression is a string of characters that describes a character sequence. This general description, called a pattern, can then be used to find matches in other character sequences. Regular expressions can specify wildcard characters, sets of characters, and various quantifiers. Thus, you can specify a regular expression that represents a general form that can match several different specific character sequences.

There are two classes that support regular expression processing: Pattern and Matcher. These classes work together. Use Pattern to define a regular expression. Match the pattern against another sequence using Matcher.
Pattern

The Pattern class defines no constructors. Instead, a pattern is created by calling the compile( ) factory method. One of its forms is shown here:

```
static Pattern compile(String pattern)
```

Here, pattern is the regular expression that you want to use. The compile( ) method transforms the string in pattern into a pattern that can be used for pattern matching by the Matcher class. It returns a Pattern object that contains the pattern.

Once you have created a Pattern object, you will use it to create a Matcher. This is done by calling the matcher( ) method defined by Pattern. It is shown here:

```
Matcher matcher(CharSequence str)
```

Here str is the character sequence that the pattern will be matched against. This is called the input sequence. CharSequence is an interface that defines a read-only set of characters. It is implemented by the String class, among others. Thus, you can pass a string to matcher( ).

Matcher

The Matcher class has no constructors. Instead, you create a Matcher by calling the matcher( ) factory method defined by Pattern, as just explained. Once you have created a Matcher, you will use its methods to perform various pattern matching operations. Several are described here.

The simplest pattern matching method is matches( ), which determines whether the character sequence matches the pattern. It is shown here:

```
boolean matches( )
```

It returns true if the sequence and the pattern match, and false otherwise. Understand that the entire sequence must match the pattern, not just a subsequence of it.

To determine if a subsequence of the input sequence matches the pattern, use find( ). One version is shown here:

```
boolean find( )
```

It returns true if there is a matching subsequence and false otherwise. This method can be called repeatedly, allowing it to find all matching subsequences. Each call to
find( ) begins where the previous one left off.

You can obtain a string containing the last matching sequence by calling group( ). One of its forms is shown here:

String group( )

The matching string is returned. If no match exists, then an IllegalStateException is thrown.

You can obtain the index within the input sequence of the current match by calling start( ). The index one past the end of the current match is obtained by calling end( ). The forms used in this chapter are shown here:

int start( )
int end( )

Both throw IllegalStateException if no match exists.

You can replace all occurrences of a matching sequence with another sequence by calling replaceAll( ). One version is shown here:

String replaceAll(String newStr)

Here, newStr specifies the new character sequence that will replace the ones that match the pattern. The updated input sequence is returned as a string.

Regular Expression Syntax

Before demonstrating Pattern and Matcher, it is necessary to explain how to construct a regular expression. Although no rule is complicated by itself, there are a large number of them, and a complete discussion is beyond the scope of this chapter. However, a few of the more commonly used constructs are described here.

In general, a regular expression is comprised of normal characters, character classes (sets of characters), wildcard characters, and quantifiers. A normal character is matched as-is. Thus, if a pattern consists of "xy", then the only input sequence that will match it is "xy". Characters such as newline and tab are specified using the standard escape sequences, which begin with a \. For example, a newline is specified by \n. In the language of regular expressions, a normal character is also called a literal.

A character class is a set of characters. A character class is specified by putting the characters in the class between brackets. For example, the class [wxyz] matches w, x, y, or z. To specify an inverted set, precede the characters with a ^. For
example, [^wxyz] matches any character except w, x, y, or z. You can specify a range of characters using a hyphen. For example, to specify a character class that will match the digits 1 through 9, use [1-9].

The wildcard character is the . (dot) and it matches any character. Thus, a pattern that consists of "." will match these (and other) input sequences: "A", "a", "x", and so on.

A quantifier determines how many times an expression is matched. The basic quantifiers are shown here:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Match one or more.</td>
</tr>
<tr>
<td>*</td>
<td>Match zero or more.</td>
</tr>
<tr>
<td>?</td>
<td>Match zero or one.</td>
</tr>
</tbody>
</table>

For example, the pattern "x+" will match "x", "xx", and "xxx", among others. As you will see, variations are supported that affect how matching is performed.

One other point: In general, if you specify an invalid expression, a `PatternSyntaxException` will be thrown.

**Demonstrating Pattern Matching**

The best way to understand how regular expression pattern matching operates is to work through some examples. The first, shown here, looks for a match with a literal pattern:
The output from the program is shown here:

Testing Java against Java.
Matches

Testing Java against Java 9.
No Match

Let’s look closely at this program. The program begins by creating the pattern that contains the sequence "Java". Next, a Matcher is created for that pattern that has the input sequence "Java". Then, the matches( ) method is called to determine if the input sequence matches the pattern. Because the sequence and the pattern are the same, matches( ) returns true. Next, a new Matcher is created with the input sequence "Java 9" and matches( ) is called again. In this case, the pattern and the
input sequence differ, and no match is found. Remember, the `matches()` function returns `true` only when the input sequence precisely matches the pattern. It will not return `true` just because a subsequence matches.

You can use `find()` to determine if the input sequence contains a subsequence that matches the pattern. Consider the following program:

```java
// Use find() to find a subsequence.
import java.util.regex.*;

class RegExpr2 {
    public static void main(String args[]) {
        Pattern pat = Pattern.compile("Java");
        Matcher mat = pat.matcher("Java 9");

        System.out.println("Looking for Java in Java 9.");

        if(mat.find()) System.out.println("subsequence found");
        else System.out.println("No Match");
    }
}
```

The output is shown here:

```
Looking for Java in Java 9.
subsequence found
```

In this case, `find()` finds the subsequence "Java".

The `find()` method can be used to search the input sequence for repeated occurrences of the pattern because each call to `find()` picks up where the previous one left off. For example, the following program finds two occurrences of the pattern "test":

```java
```
As the output shows, two matches were found. The program uses the `start()` method to obtain the index of each match.

### Using Wildcards and Quantifiers

Although the preceding programs show the general technique for using `Pattern` and `Matcher`, they don’t show their power. The real benefit of regular expression processing is not seen until wildcards and quantifiers are used. To begin, consider the following example that uses the `+` quantifier to match any arbitrarily long sequence of Ws:

```java
// Use a quantifier.
import java.util.regex.*;

class RegExpr4 {
    public static void main(String args[]) {
        Pattern pat = Pattern.compile("W+");
        Matcher mat = pat.matcher("W WW WWW");

        while(mat.find())
            System.out.println("Match: " + mat.group());
    }
}
```
The output from the program is shown here:

```
Match: W
Match: WW
Match: WWW
```

As the output shows, the regular expression pattern "W+" matches any arbitrarily long sequence of Ws.

The next program uses a wildcard to create a pattern that will match any sequence that begins with e and ends with d. To do this, it uses the dot wildcard character along with the + quantifier.

```
// Use wildcard and quantifier.
import java.util.regex.*;

class RegExpr5 {
    public static void main(String args[]) {
        Pattern pat = Pattern.compile("e.+d");
        Matcher mat = pat.matcher("extend cup end table");

        while(mat.find())
            System.out.println("Match: " + mat.group());
    }
}
```

You might be surprised by the output produced by the program, which is shown here:

```
Match: extend cup end
```

Only one match is found, and it is the longest sequence that begins with e and ends with d. You might have expected two matches: "extend" and "end". The reason that the longer sequence is found is that the pattern "e.+d" matches the longest sequence that fits the pattern. This is called greedy behavior. You can specify reluctant behavior by adding the ? to the pattern, as shown in this version of the program. It causes the shortest matching pattern to be obtained.
The output from the program is shown here:

Match: extend
Match: end

As the output shows, the pattern "e.+?d" will match the shortest sequence that begins with e and ends with d. Thus, two matches are found.

In general, to convert a greedy quantifier into a reluctant quantifier, add a ?. You can also specify possessive behavior by appending a +. For example, you might want to try the pattern "e.?+d" and observe the result. You can also specify a number of times to match by using \{min, limit\}, which matches min times, up to limit times. Also supported are \{min\} and \{min,\} which match min times, and min times but possibly more, respectively.

Working with Classes of Characters

Sometimes you will want to match any sequence that contains one or more characters, in any order, that are part of a set of characters. For example, to match whole words, you want to match any sequence of the letters of the alphabet. One of the easiest ways to do this is to use a character class, which defines a set of characters. Recall that a character class is created by putting the characters you want to match between brackets. For example, to match the lowercase characters a through z, use [a-z]. The following program demonstrates this technique:
Using replaceAll( )

The replaceAll( ) method supplied by Matcher lets you perform powerful search and replace operations that use regular expressions. For example, the following program replaces all occurrences of sequences that begin with "Jon" with "Eric":

```java
import java.util.regex.*;

class RegExpr7 {
    public static void main(String args[]) {
        // Match lowercase words.
        Pattern pat = Pattern.compile("[a-z]+");
        Matcher mat = pat.matcher("this is a test.");

        while(mat.find())
            System.out.println("Match: " + mat.group());
    }
}

The output is shown here:

    Match: this
    Match: is
    Match: a
    Match: test
```
Because the regular expression "Jon.*? " matches any string that begins with Jon followed by zero or more characters, ending in a space, it can be used to match and replace both Jon and Jonathan with the name Eric. Such a substitution is not easily accomplished without pattern matching capabilities.

Using split()
You can reduce an input sequence into its individual tokens by using the split() method defined by Pattern. One form of the split() method is shown here:

```java
String[ ] split(CharSequence str)
```

It processes the input sequence passed in `str`, reducing it into tokens based on the delimiters specified by the pattern.

For example, the following program finds tokens that are separated by spaces, commas, periods, and exclamation points:

```java
// Use replaceAll().
import java.util.regex.*;

class RegExpr8 {
    public static void main(String args[]) {
        String str = "Jon Jonathan Frank Ken Todd";

        Pattern pat = Pattern.compile("Jon.*? ");
        Matcher mat = pat.matcher(str);

        System.out.println("Original sequence: " + str);
        str = mat.replaceAll("Eric ");

        System.out.println("Modified sequence: " + str);
    }
}
```

The output is shown here:

```
Original sequence: Jon Jonathan Frank Ken Todd
Modified sequence: Eric Eric Frank Ken Todd
```
As the output shows, the input sequence is reduced to its individual tokens. Notice that the delimiters are not included.

Two Pattern-Matching Options

Although the pattern-matching techniques described in the foregoing offer the greatest flexibility and power, there are two alternatives which you might find useful in some circumstances. If you only need to perform a one-time pattern match, you can use the `matches()` method defined by `Pattern`. It is shown here:

```java
static boolean matches(String pattern, CharSequence str)
```

It returns `true` if `pattern` matches `str` and `false` otherwise. This method automatically compiles `pattern` and then looks for a match. If you will be using the same pattern repeatedly, then using `matches()` is less efficient than compiling the pattern and using the pattern-matching methods defined by `Matcher`, as described previously.

You can also perform a pattern match by using the `matches()` method implemented by `String`. It is shown here:
boolean matches(String pattern)

If the invoking string matches the regular expression in pattern, then matches() returns true. Otherwise, it returns false.

Exploring Regular Expressions

The overview of regular expressions presented in this section only hints at their power. Since text parsing, manipulation, and tokenization are a large part of programming, you will likely find Java’s regular expression subsystem a powerful tool that you can use to your advantage. It is, therefore, wise to explore the capabilities of regular expressions. Experiment with several different types of patterns and input sequences. Once you understand how regular expression pattern matching works, you will find it useful in many of your programming endeavors.

Reflection

Reflection is the ability of software to analyze itself. This is provided by the java.lang.reflect package and elements in Class. Beginning with JDK 9, java.lang.reflect is part of the java.base module. Reflection is an important capability, especially when using components called Java Beans. It allows you to analyze a software component and describe its capabilities dynamically, at run time rather than at compile time. For example, by using reflection, you can determine what methods, constructors, and fields a class supports. Reflection was introduced in Chapter 12. It is examined further here.

The package java.lang.reflect includes several interfaces. Of special interest is Member, which defines methods that allow you to get information about a field, constructor, or method of a class. There are also ten classes in this package. These are listed in Table 30-1.
The following application illustrates a simple use of the Java reflection capabilities. It prints the constructors, fields, and methods of the class `java.awt.Dimension`. The program begins by using the `forName()` method of `Class` to get a class object for `java.awt.Dimension`. Once this is obtained, `getConstructors()`, `getFields()`, and `getMethods()` are used to analyze this class object. They return arrays of `Constructor`, `Field`, and `Method` objects that provide the information about the object. The `Constructor`, `Field`, and `Method` classes define several methods that can be used to obtain information about an object. You will want to explore these on your own. However, each supports the `toString()` method. Therefore, using `Constructor`, `Field`, and `Method` objects as arguments to the `println()` method is straightforward, as shown in the program.

```java
// Demonstrate reflection.
import java.lang.reflect.*;
public class ReflectionDemo1 {
    public static void main(String args[]) {
        try {
            Class<?> c = Class.forName("java.awt.Dimension");
            System.out.println("Constructors:");
            Constructor<?> constructors[] = c.getConstructors();
```
for(int i = 0; i < constructors.length; i++) {
    System.out.println(" " + constructors[i]);
}

System.out.println("Fields:");
Field fields[] = c.getFields();
for(int i = 0; i < fields.length; i++) {
    System.out.println(" " + fields[i]);
}

System.out.println("Methods:");
Method methods[] = c.getMethods();
for(int i = 0; i < methods.length; i++) {
    System.out.println(" " + methods[i]);
}
}
catch(Exception e) {
    System.out.println("Exception: " + e);
}
}

Here is the output from this program. (The output you see when you run the program may differ slightly from that shown.)
The next example uses Java’s reflection capabilities to obtain the public methods of a class. The program begins by instantiating class `A`. The `getClass()` method is applied to this object reference, and it returns the `Class` object for class `A`. The `getDeclaredMethods()` method returns an array of `Method` objects that describe only the methods declared by this class. Methods inherited from superclasses such as `Object` are not included.

Each element of the `methods` array is then processed. The `getModifiers()` method returns an `int` containing flags that describe which modifiers apply for this element. The `Modifier` class provides a set of `isX` methods, shown in Table 30-2, that can be used to examine this value. For example, the static method `isPublic()` returns `true` if its argument includes the `public` modifier. Otherwise, it returns `false`. In the following program, if the method supports public access, its name is obtained by the `getName()` method and is then printed.
// Show public methods.
import java.lang.reflect.*;
public class ReflectionDemo2 {
    public static void main(String args[]) {

        try {
            A a = new A();
            Class<?> c = a.getClass();
            System.out.println("Public Methods: ");
            Method methods[] = c.getDeclaredMethods();
            for(int i = 0; i < methods.length; i++) {
                int modifiers = methods[i].getModifiers();
                if(Modifier.isPublic(modifiers)) {
                    System.out.println(" " + methods[i].getName());
                }
            }
            catch(Exception e) {
                System.out.println("Exception: " + e);
            }
        }

    class A {
        public void a1() {
        }
        public void a2() {
        }
        protected void a3() {
        }
        private void a4() {
        }
    }
}
Table 30-2  The “is” Methods Defined by Modifier That Determine Modifiers

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static boolean isAbstract(int val)</td>
<td>Returns true if val has the abstract flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isFinal(int val)</td>
<td>Returns true if val has the final flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isInterface(int val)</td>
<td>Returns true if val has the interface flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isNative(int val)</td>
<td>Returns true if val has the native flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isPrivate(int val)</td>
<td>Returns true if val has the private flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isProtected(int val)</td>
<td>Returns true if val has the protected flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isPublic(int val)</td>
<td>Returns true if val has the public flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isStatic(int val)</td>
<td>Returns true if val has the static flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isStrict(int val)</td>
<td>Returns true if val has the strict flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isSynchronized(int val)</td>
<td>Returns true if val has the synchronized flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isTransient(int val)</td>
<td>Returns true if val has the transient flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isVolatile(int val)</td>
<td>Returns true if val has the volatile flag set and false otherwise.</td>
</tr>
</tbody>
</table>

Here is the output from this program:

```
    Public Methods:
        a1
        a2
```

**Modifier** also includes a set of static methods that return the type of modifiers that can be applied to a specific type of program element. These methods are
static int classModifiers( )
static int constructorModifiers( )
static int fieldModifiers( )
static int interfaceModifiers( )
static int methodModifiers( )
static int parameterModifiers( )

For example, `methodModifiers()` returns the modifiers that can be applied to a method. Each method returns flags, packed into an `int`, that indicate which modifiers are legal. The modifier values are defined by constants in `Modifier`, which include `PROTECTED`, `PUBLIC`, `PRIVATE`, `STATIC`, `FINAL`, and so on.

**Remote Method Invocation (RMI)**

Remote Method Invocation (RMI) allows a Java object that executes on one machine to invoke a method of a Java object that executes on another machine. This is an important feature, because it allows you to build distributed applications. While a complete discussion of RMI is outside the scope of this book, the following simplified example describes the basic principles involved. RMI is supported by the `java.rmi` package. Beginning with JDK 9, it is part of the `java.rmi` module.

**A Simple Client/Server Application Using RMI**

This section provides step-by-step directions for building a simple client/server application by using RMI. The server receives a request from a client, processes it, and returns a result. In this example, the request specifies two numbers. The server adds these together and returns the sum.

**Step One: Enter and Compile the Source Code**

This application uses four source files. The first file, `AddServerIntf.java`, defines the remote interface that is provided by the server. It contains one method that accepts two `double` arguments and returns their sum. All remote interfaces must extend the `Remote` interface, which is part of `java.rmi`. `Remote` defines no members. Its purpose is simply to indicate that an interface uses remote methods. All remote methods can throw a `RemoteException`. 
The second source file, `AddServerImpl.java`, implements the remote interface. The implementation of the `add()` method is straightforward. Remote objects typically extend `UnicastRemoteObject`, which provides functionality that is needed to make objects available from remote machines.

```java
import java.rmi.*;

public interface AddServerIntf extends Remote {
    double add(double d1, double d2) throws RemoteException;
}
```

The third source file, `AddServer.java`, contains the main program for the server machine. Its primary function is to update the RMI registry on that machine. This is done by using the `rebind()` method of the `Naming` class (found in `java.rmi`). That method associates a name with an object reference. The first argument to the `rebind()` method is a string that names the server as "AddServer". Its second argument is a reference to an instance of `AddServerImpl`.

```java
import java.rmi.*;
import java.rmi.server.*;

public class AddServerImpl extends UnicastRemoteObject
    implements AddServerIntf {

    public AddServerImpl() throws RemoteException {
    }
    public double add(double d1, double d2) throws RemoteException {
        return d1 + d2;
    }
}
```
import java.net.*;
import java.rmi.*;

public class AddServer {
    public static void main(String args[]) {

        try {
            AddServerImpl addServerImpl = new AddServerImpl();
            Naming.rebind("AddServer", addServerImpl);
        }
        catch(Exception e) {
            System.out.println("Exception: " + e);
        }
    }
}

The fourth source file, AddClient.java, implements the client side of this distributed application. AddClient.java requires three command-line arguments. The first is the IP address or name of the server machine. The second and third arguments are the two numbers that are to be summed.

The application begins by forming a string that follows the URL syntax. This URL uses the rmi protocol. The string includes the IP address or name of the server and the string "AddServer". The program then invokes the lookup( ) method of the Naming class. This method accepts one argument, the rmi URL, and returns a reference to an object of type AddServerIntf. All remote method invocations can then be directed to this object.

The program continues by displaying its arguments and then invokes the remote add( ) method. The sum is returned from this method and is then printed.
import java.rmi. *;

public class AddClient {
    public static void main(String args[]) {
        try {
            String addServerURL = "rmi://" + args[0] + "/AddServer";
            AddServerIntf addServerIntf =
                (AddServerIntf)Naming.lookup(addServerURL);
            System.out.println("The first number is: " + args[1]);
            double d1 = Double.valueOf(args[1]).doubleValue();
            System.out.println("The second number is: " + args[2]);
            double d2 = Double.valueOf(args[2]).doubleValue();
            System.out.println("The sum is: " + addServerIntf.add(d1, d2));
        } catch (Exception e) {
            System.out.println("Exception: " + e);
        }
    }
}

After you enter all the code, use javac to compile the four source files that you created.

**Step Two: Manually Generate a Stub if Required**

In the context of RMI, a **stub** is a Java object that resides on the client machine. Its function is to present the same interfaces as the remote server. Remote method calls initiated by the client are actually directed to the stub. The stub works with the other parts of the RMI system to formulate a request that is sent to the remote machine.

A remote method may accept arguments that are simple types or objects. In the latter case, the object may have references to other objects. All of this information must be sent to the remote machine. That is, an object passed as an argument to a remote method call must be serialized and sent to the remote machine. Recall from Chapter 21 that the serialization facilities also recursively process all referenced objects.

If a response must be returned to the client, the process works in reverse. Note that the serialization and deserialization facilities are also used if objects are returned to a client.

Prior to Java 5, stubs needed to be built manually by using rmic. This step is not required for modern versions of Java. However, if you are working in a legacy
environment, then you can use the `rmic` compiler, as shown here, to build a stub:

```
rmic AddServerImpl
```

This command generates the file `AddServerImpl_Stub.class`. When using `rmic`, be sure that `CLASSPATH` is set to include the current directory.

**Step Three: Install Files on the Client and Server Machines**

Copy `AddClient.class`, `AddServerImpl_Stub.class` (if needed), and `AddServerIntf.class` to a directory on the client machine. Copy `AddServerIntf.class`, `AddServerImpl.class`, `AddServerImpl_Stub.class` (if needed), and `AddServer.class` to a directory on the server machine.

---

**NOTE** RMI has techniques for dynamic class loading, but they are not used by the example at hand. Instead, all of the files that are used by the client and server applications must be installed manually on those machines.

**Step Four: Start the RMI Registry on the Server Machine**

The JDK provides a program called `rmiregistry`, which executes on the server machine. It maps names to object references. First, check that the `CLASSPATH` environment variable includes the directory in which your files are located. Then, start the RMI Registry from the command line, as shown here:

```
start rmiregistry
```

When this command returns, you should see that a new window has been created. You need to leave this window open until you are done experimenting with the RMI example.

**Step Five: Start the Server**

The server code is started from the command line, as shown here:

```
java AddServer
```

Recall that the `AddServer` code instantiates `AddServerImpl` and registers that object with the name "AddServer".

**Step Six: Start the Client**

The `AddClient` software requires three arguments: the name or IP address of the
server machine and the two numbers that are to be summed together. You may invoke it from the command line by using one of the two formats shown here:

```
java AddClient server1 8 9
java AddClient 11.12.13.14 8 9
```

In the first line, the name of the server is provided. The second line uses its IP address (11.12.13.14).

You can try this example without actually having a remote server. To do so, simply install all of the programs on the same machine, start `rmiregistry`, start `AddServer`, and then execute `AddClient` using this command line:

```
java AddClient 127.0.0.1 8 9
```

Here, the address 127.0.0.1 is the “loop back” address for the local machine. Using this address allows you to exercise the entire RMI mechanism without actually having to install the server on a remote computer. (If you are using a firewall, then this approach may not work.)

In either case, sample output from this program is shown here:

```
The first number is: 8
The second number is: 9
The sum is: 17.0
```

NOTE When working with RMI in the real world, it may be necessary for the server to install a security manager.

### Formatting Date and Time with java.text

The package `java.text` allows you to format, parse, search, and manipulate text. Beginning with JDK 9, `java.text` is part of the `java.base` module. This section examines two of `java.text`'s most commonly used classes: those that format date and time information. However, it is important to state at the outset that the new date and time API described later in this chapter offers a modern approach to handling date and time that also supports formatting. Of course, legacy code will continue to use the classes shown here for some time.

#### DateFormat Class

`DateFormat` is an abstract class that provides the ability to format and parse dates and times. The `getDateTimeInstance()` method returns an instance of `DateFormat` that
can format date information. It is available in these forms:

```java
static final DateFormat getDateInstance()
static final DateFormat getDateInstance(int style)
static final DateFormat getDateInstance(int style, Locale locale)
```

Here, `style` is one of the following values: `DEFAULT`, `SHORT`, `MEDIUM`, `LONG`, or `FULL`. These are `int` constants defined by `DateFormat`. They cause different details about the date to be presented. The parameter `locale` specifies the locale (refer to Chapter 20 for details on `Locale`). If the `style` and/or `locale` is not specified, defaults are used.

One of the most commonly used methods in this class is `format()`. It has several overloaded forms, one of which is shown here:

```java
final String format(Date d)
```

The argument is a `Date` object that is to be displayed. The method returns a string containing the formatted information.

The following listing illustrates how to format date information. It begins by creating a `Date` object. This captures the current date and time information. Then it outputs the date information by using different styles and locales.
Sample output from this program is shown here:

Japan: 14/01/01
Korea: 2017. 1. 1
United Kingdom: 1 January 2014
United States: Sunday, January 1, 2017

The `getTimeInstance()` method returns an instance of `DateFormat` that can format time information. It is available in these versions:

```java
static final DateFormat getTimeInstance()
static final DateFormat getTimeInstance(int style)
static final DateFormat getTimeInstance(int style, Locale locale)
```

Here, `style` is one of the following values: `DEFAULT`, `SHORT`, `MEDIUM`, `LONG`, or `FULL`. These are `int` constants defined by `DateFormat`. They cause different details about the time to be presented. The parameter `locale` specifies the locale. If the `style` and/or `locale` is not specified, defaults are used.

The following listing illustrates how to format time information. It begins by
creating a `Date` object. This captures the current date and time information. Then it outputs the time information by using different styles and locales.

```java
// Demonstrate time formats.
import java.text.*;
import java.util.*;
public class TimeFormatDemo {
    public static void main(String args[]) {
        Date date = new Date();
        DateFormat df;

        df = DateFormat.getTimeInstance(DateFormat.SHORT, Locale.JAPAN);
        System.out.println("Japan: " + df.format(date));

        df = DateFormat.getTimeInstance(DateFormat.LONG, Locale.UK);
        System.out.println("United Kingdom: " + df.format(date));

        df = DateFormat.getTimeInstance(DateFormat.FULL, Locale.CANADA);
        System.out.println("Canada: " + df.format(date));
    }
}

Sample output from this program is shown here:

Japan: 13:03
United Kingdom: 13:03:31 GMT-06:00
Canada: 1:03:31 PM Central Standard Time

The `DateFormat` class also has a `getTimeInstance()` method that can format both date and time information. You may wish to experiment with it on your own.

**SimpleDateFormat Class**

`SimpleDateFormat` is a concrete subclass of `DateFormat`. It allows you to define your own formatting patterns that are used to display date and time information.

One of its constructors is shown here:

`SimpleDateFormat(String formatString)`

The argument `formatString` describes how date and time information is displayed. An example of its use is given here:

```java
SimpleDateFormat sdf = SimpleDateFormat("dd MMM yyyy hh:mm:ss zzz");
```
The symbols used in the formatting string determine the information that is displayed. Table 30-3 lists these symbols and gives a description of each.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>a</code></td>
<td>AM or PM</td>
</tr>
<tr>
<td><code>d</code></td>
<td>Day of month (1–31)</td>
</tr>
<tr>
<td><code>h</code></td>
<td>Hour in AM/PM (1–12)</td>
</tr>
<tr>
<td><code>k</code></td>
<td>Hour in day (1–24)</td>
</tr>
<tr>
<td><code>m</code></td>
<td>Minute in hour (0–59)</td>
</tr>
<tr>
<td><code>s</code></td>
<td>Second in minute (0–59)</td>
</tr>
<tr>
<td><code>u</code></td>
<td>Day of week, with Monday being 1</td>
</tr>
<tr>
<td><code>w</code></td>
<td>Week of year (1–52)</td>
</tr>
<tr>
<td><code>y</code></td>
<td>Year</td>
</tr>
<tr>
<td><code>z</code></td>
<td>Time zone</td>
</tr>
<tr>
<td><code>D</code></td>
<td>Day of year (1–366)</td>
</tr>
<tr>
<td><code>E</code></td>
<td>Day of week (for example, Thursday)</td>
</tr>
<tr>
<td><code>F</code></td>
<td>Day of week in month</td>
</tr>
<tr>
<td><code>G</code></td>
<td>Era (for example, AD or BC)</td>
</tr>
<tr>
<td><code>H</code></td>
<td>Hour in day (0–23)</td>
</tr>
<tr>
<td><code>K</code></td>
<td>Hour in AM/PM (0–11)</td>
</tr>
<tr>
<td><code>L</code></td>
<td>Month</td>
</tr>
<tr>
<td><code>M</code></td>
<td>Month</td>
</tr>
<tr>
<td><code>S</code></td>
<td>Millisecond in second</td>
</tr>
<tr>
<td><code>W</code></td>
<td>Week of month (1–5)</td>
</tr>
<tr>
<td><code>X</code></td>
<td>Time zone in ISO 8601 format</td>
</tr>
<tr>
<td><code>Y</code></td>
<td>Week year</td>
</tr>
<tr>
<td><code>Z</code></td>
<td>Time zone in RFC 822 format</td>
</tr>
</tbody>
</table>

**Table 30-3** Formatting String Symbols for [SimpleDateFormat](http://example.com)

In most cases, the number of times a symbol is repeated determines how that data is presented. Text information is displayed in an abbreviated form if the pattern letter
is repeated less than four times. Otherwise, the unabbreviated form is used. For example, a zzzz pattern can display Pacific Daylight Time, and a zzz pattern can display PDT.

For numbers, the number of times a pattern letter is repeated determines how many digits are presented. For example, hh:mm:ss can present 01:51:15, but h:m:s displays the same time value as 1:51:15.

Finally, M or MM causes the month to be displayed as one or two digits. However, three or more repetitions of M cause the month to be displayed as a text string.

The following program shows how this class is used:

```java
// Demonstrate SimpleDateFormat.
import java.text.*;
import java.util.*;

public class SimpleDateFormatDemo {
    public static void main(String args[]) {
        Date date = new Date();
        SimpleDateFormat sdf;
        sdf = new SimpleDateFormat("hh:mm:ss");
        System.out.println(sdf.format(date));
        sdf = new SimpleDateFormat("dd MMM yyyy hh:mm:ss zzz");
        System.out.println(sdf.format(date));
        sdf = new SimpleDateFormat("E MMM dd yyyy");
        System.out.println(sdf.format(date));
    }
}
```

Sample output from this program is shown here:

```
01:30:51
01 Jan 2017 01:30:51 CST
Sun Jan 01 2017
```

**The java.time Time and Date API**

In Chapter 20, Java’s long-standing approach to handling date and time through the use of classes such as Calendar and GregorianCalendar was discussed. It is expected that this traditional approach will remain in widespread use for some time and is, therefore, something that all Java programmers need to be familiar with. However, beginning with JDK 8, Java includes another approach to handling time
and date. This new approach is defined in the following packages:

<table>
<thead>
<tr>
<th>Package</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>java.time</td>
<td>Provides top-level classes that support time and date.</td>
</tr>
<tr>
<td>java.time.chrono</td>
<td>Supports alternative, non-Gregorian calendars.</td>
</tr>
<tr>
<td>java.time.format</td>
<td>Supports time and date formatting.</td>
</tr>
<tr>
<td>java.time.temporal</td>
<td>Supports extended date and time functionality.</td>
</tr>
<tr>
<td>java.time.zone</td>
<td>Supports time zones.</td>
</tr>
</tbody>
</table>

These packages define a large number of classes, interfaces, and enumerations that provide extensive, finely grained support for time and date operations. Because of the number of elements that comprise the new time and date API, it can seem fairly intimidating at first. However, it is well organized and logically structured. Its size reflects the detail of control and flexibility that it provides. Although it is far beyond the scope of this book to examine each element in this extensive API, we will look at several of its main classes. As you will see, these classes are sufficient for many uses. Beginning with JDK 9, these packages are in the **java.base** module.

**Time and Date Fundamentals**

In **java.time** are defined several top-level classes that give you easy access to the time and date. Three of these are **LocalDate**, **LocalTime**, and **LocalDateTime**. They are value-based, and as their names suggest, they encapsulate the local date, time, and date and time. Using these classes, it is easy to obtain the current date and time, format the date and time, and compare dates and times, among other operations.

**LocalDate** encapsulates a date that uses the default Gregorian calendar as specified by ISO 8601. **LocalTime** encapsulates a time, as specified by ISO 8601. **LocalDateTime** encapsulates both date and time. These classes contain a large number of methods that give you access to the date and time components, allow you to compare dates and times, add or subtract date or time components, and so on. Because a common naming convention for methods is employed, once you know how to use one of these classes, the others are easy to master.

**LocalDate**, **LocalTime**, and **LocalDateTime** do not define public constructors. Rather, to obtain an instance, you will use a factory method. One very convenient method is `now()`, which is defined for all three classes. It returns the current date and/or time of the system. Each class defines several versions, but we will use its simplest form. Here is the version we will use as defined by **LocalDate**:
static LocalDate now( )

The version for **LocalTime** is shown here:

static LocalTime now( )

The version for **LocalDateTime** is shown here:

    static LocalDateTime now( )

    As you can see, in each case, an appropriate object is returned. The object returned
    by **now()** can be displayed in its default, human-readable form by use of a **println()**
    statement, for example. However, it is also possible to take full control over the
    formatting of date and time.

    The following program uses **LocalDate** and **LocalTime** to obtain the current date
    and time and then displays them. Notice how **now()** is called to retrieve the current
    date and time.

    // A simple example of LocalDate and LocalTime.
    import java.time.*;

    class DateTimeDemo {
        public static void main(String args[]) {

            LocalDate curDate = LocalDate.now();
            System.out.println(curDate);

            LocalTime curTime = LocalTime.now();
            System.out.println(curTime);
        }
    }

    Sample output is shown here:

    2017-01-01
    14:03:41.436

    The output reflects the default format that is given to the date and time. (The next
    section shows how to specify a different format.)

    Because the preceding program displays both the current date and the current
    time, it could have been more easily written using the **LocalDateTime** class. In this
    approach, only a single instance needs to be created and only a single call to **now( )**
    is required, as shown here:
Using this approach, the default output includes both date and time. Here is a sample:

2017-01-01T14:04:56.799

One other point: from a `LocalDateTime` instance, it is possible to obtain a reference to the date or time component by using the `toLocalDate()` and `toLocalTime()` methods, shown here:

```java
LocalDate toLocalDate()
LocalTime toLocalTime()
```

Each returns a reference to the indicated element.

**Formatting Date and Time**

Although the default formats shown in the preceding examples will be adequate for some uses, often you will want to specify a different format. Fortunately, this is easy to do because `LocalDate`, `LocalTime`, and `LocalDateTime` all provide the `format()` method, shown here:

```java
String format(DateTimeFormatter fmtr)
```

Here, `fmtr` specifies the instance of `DateTimeFormatter` that will provide the format.

`DateTimeFormatter` is packaged in `java.time.format`. To obtain a `DateTimeFormatter` instance, you will typically use one of its factory methods. Three are shown here:

```java
static DateTimeFormatter ofLocalizedDate(FormatStyle fmtDate)
static DateTimeFormatter ofLocalizedTime(FormatStyle fmtTime)
static DateTimeFormatter ofLocalizedDateTime(FormatStyle fmtDate,
FormatStyle fmtTime)
```

Of course, the type of `DateTimeFormatter` that you create will be based on the type of object it will be operating on. For example, if you want to format the date in a `LocalDate` instance, then use `ofLocalizedDate()`. The specific format is specified by the `FormatStyle` parameter.
**FormatStyle** is an enumeration that is packaged in `java.time.format`. It defines the following constants:

- FULL
- LONG
- MEDIUM
- SHORT

These specify the level of detail that will be displayed. (Thus, this form of `DateTimeFormatter` works similarly to `java.text.SimpleDateFormat`, described earlier in this chapter.)

Here is an example that uses `DateTimeFormatter` to display the current date and time:

```java
// Demonstrate DateTimeFormatter.
import java.time.*;
import java.time.format.*;

class DateTimeDemo2 {
    public static void main(String args[]) {
        LocalDate curDate = LocalDate.now();
        System.out.println(curDate.format(
            DateTimeFormatter.ofLocalizedDate(FormatStyle.FULL)));

        LocalTime curTime = LocalTime.now();
        System.out.println(curTime.format(
            DateTimeFormatter.ofLocalizedTime(FormatStyle.SHORT)));
    }
}
```

Sample output is shown here:

```
Sunday, January 1, 2017
2:16 PM
```

In some situations, you may want a format different from the ones you can specify by use of **FormatStyle**. One way to accomplish this is to use a predefined formatter, such as `ISO_DATE` or `ISO_TIME`, provided by `DateTimeFormatter`. Another way is to create a custom format by specifying a pattern. To do this, you can use the `ofPattern()` factory method of `DateTimeFormatter`. One version is shown
static DateTimeFormatter ofPattern(String fmtPattern)

Here, \texttt{fmtPattern} specifies a string that contains the date and time pattern that you want. It returns a \texttt{DateTimeFormatter} that will format according to that pattern. The default locale is used.

In general, a pattern consists of format specifiers, called \textit{pattern letters}. A pattern letter will be replaced by the date or time component that it specifies. The full list of pattern letters is shown in the API documentation for \texttt{ofPattern( )}. Here is a sampling. Note that the pattern letters are case-sensitive.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>AM/PM indicator</td>
</tr>
<tr>
<td>d</td>
<td>Day in month</td>
</tr>
<tr>
<td>E</td>
<td>Day in week</td>
</tr>
<tr>
<td>h</td>
<td>Hour, 12-hour clock</td>
</tr>
<tr>
<td>H</td>
<td>Hour, 24-hour clock</td>
</tr>
<tr>
<td>M</td>
<td>Month</td>
</tr>
<tr>
<td>m</td>
<td>Minutes</td>
</tr>
<tr>
<td>s</td>
<td>Seconds</td>
</tr>
<tr>
<td>y</td>
<td>Year</td>
</tr>
</tbody>
</table>

In general, the precise output that you see will be determined by how many times a pattern letter is repeated. (Thus, \texttt{DateTimeFormatter} works a bit like \texttt{java.text.SimpleDateFormat}, described earlier in this chapter.) For example, assuming that the month is April, the patterns:

\texttt{M MM MMM MMMM}

produce the following formatted output:

\texttt{4 04 Apr April}

Frankly, experimentation is the best way to understand what each pattern letter does and how various repetitions affect the output.

When you want to output a pattern letter as text, enclose the text between single quotation marks. In general, it is a good idea to enclose all non-pattern characters within single quotation marks to avoid problems if the set of pattern letters changes
in subsequent versions of Java.

The following program demonstrates the use of a date and time pattern:

```java
// Create a custom date and time format.
import java.time.*;
import java.time.format.*;

class DateTimeDemo3 {
    public static void main(String args[]) {
        
        LocalDate curDateTime = LocalDate.now();
        System.out.println(curDateTime.format(
            DateTimeFormatter.ofPattern("MMMM d',' yyyy h':'mm a")));
    }
}
```

Sample output is shown here:

```
January 1, 2017 2:22 PM
```

One other point about creating custom date and time output: `LocalDate`, `LocalTime`, and `LocalDateTime` define methods that let you obtain various date and time components. For example, `getHour()` returns the hour as an `int`; `getMonth()` returns the month in the form of a `Month` enumeration value; and `getYear()` returns the year as an `int`. Using these, and other methods, you can manually construct output. You can also use these values for other purposes, such as when creating specialized timers.

### Parsing Date and Time Strings

`LocalDate`, `LocalTime`, and `LocalDateTime` provide the ability to parse date and/or time strings. To do this, call `parse()` on an instance of one of those classes. It has two forms. The first uses the default formatter that parses the date and/or time formatted in the standard ISO fashion, such as 03:31 for time and 2020-08-02 for date. The form of this version of `parse()` for `LocalDateTime` is shown here. (Its form for the other classes is similar except for the type of object returned.)

```
static LocalDateTime parse(CharSequence dateTimeStr)
```

Here, `dateTimeStr` is a string that contains the date and time in the proper format. If the format is invalid, an exception will be thrown.

If you want to parse a date and/or time string that is in a format other than ISO format, you can use a second form of `parse()` that lets you specify your own
formatter. The version specified by **LocalDateTime** is shown next. (The other classes provide a similar form except for the return type.)

```java
static LocalDateTime parse(CharSequence dateTimeStr, DateTimeFormatter dateTimeFmtr)
```

Here, `dateTimeFmtr` specifies the formatter that you want to use.

Here is a simple example that parses a date and time string by use of a custom formatter:

```java
// Parse a date and time.
import java.time.*;
import java.time.format.*;

class DateTimeDemo4 {
    public static void main(String args[]) {

        // Obtain a LocalDateTime object by parsing a date and time string.
        LocalDateTime curDateTime =
            LocalDateTime.parse("June 21, 2017 12:01 AM",
            DateTimeFormatter.ofPattern("MMM d',' yyyy hh':'mm a"));

        // Now, display the parsed date and time.
        System.out.println(curDateTime.format(
            DateTimeFormatter.ofPattern("MMM d',' yyyy h':'mm a"));
    }
}
```

Sample output is shown here:

```
June 21, 2017 12:01 AM
```

**Other Things to Explore in java.time**

Although you will want to explore all of the date and time packages, a good place to start is with **java.time**. It contains a great deal of functionality that you may find useful. Begin by examining the methods defined by **LocalDate**, **LocalTime**, and **LocalDateTime**. Each has methods that let you add or subtract dates and/or times, adjust dates and/or times by a given component, compare dates and/or times, and create instances based on date and/or time components, among others. Other classes in **java.time** that you may find of particular interest include **Instant**, **Duration**, and **Period**. **Instant** encapsulates an instant in time. **Duration** encapsulates a length of time. **Period** encapsulates a length of date.
PART
III   Introducing GUI Programming with Swing

CHAPTER 31
Introducing Swing

CHAPTER 32
Exploring Swing

CHAPTER 33
Introducing Swing Menus
In Part II, you saw how to build very simple user interfaces with the AWT classes. Although the AWT is still a crucial part of Java, its component set is no longer widely used to create graphical user interfaces. Today, most programmers use Swing or JavaFX for this purpose. JavaFX is discussed in Part IV. Here, Swing is introduced. Swing is a framework that provides more powerful and flexible GUI components than does the AWT. As a result, it is the GUI that has been widely used by Java programmers for more than a decade.

Coverage of Swing is divided between three chapters. This chapter introduces Swing. It begins by describing Swing’s core concepts. It then presents a simple example that shows the general form of a Swing program. This is followed by an example that uses event handling. The chapter concludes by explaining how painting is accomplished in Swing. The next chapter presents several commonly used Swing components. The third chapter introduces Swing-based menus. It is important to understand that the number of classes and interfaces in the Swing packages is quite large, and they can’t all be covered in this book. (In fact, full coverage of Swing requires an entire book of its own.) However, these three chapters will give you a basic understanding of this important topic.


The Origins of Swing

Swing did not exist in the early days of Java. Rather, it was a response to deficiencies present in Java’s original GUI subsystem: the Abstract Window Toolkit. The AWT defines a basic set of controls, windows, and dialog boxes that support a usable, but limited graphical interface. One reason for the limited nature of the AWT is that it translates its various visual components into their corresponding, platform-specific equivalents, or peers. This means that the look and feel of a component is defined by the platform, not by Java. Because the AWT components use native code resources, they are referred to as heavyweight.

The use of native peers led to several problems. First, because of variations between operating systems, a component might look, or even act, differently on
different platforms. This potential variability threatened the overarching philosophy of Java: write once, run anywhere. Second, the look and feel of each component was fixed (because it is defined by the platform) and could not be (easily) changed. Third, the use of heavyweight components caused some frustrating restrictions. For example, a heavyweight component was always opaque.

Not long after Java’s original release, it became apparent that the limitations and restrictions present in the AWT were sufficiently serious that a better approach was needed. The solution was Swing. Introduced in 1997, Swing was included as part of the Java Foundation Classes (JFC). Swing was initially available for use with Java 1.1 as a separate library. However, beginning with Java 1.2, Swing (and the rest of the JFC) was fully integrated into Java.

Swing Is Built on the AWT

Before moving on, it is necessary to make one important point: although Swing eliminates a number of the limitations inherent in the AWT, Swing does not replace it. Instead, Swing is built on the foundation of the AWT. This is why the AWT is still a crucial part of Java. Swing also uses the same event handling mechanism as the AWT. Therefore, a basic understanding of the AWT and of event handling is required to use Swing. (The AWT is covered in Chapters 25 and 26. Event handling is described in Chapter 24.)

Two Key Swing Features

As just explained, Swing was created to address the limitations present in the AWT. It does this through two key features: lightweight components and a pluggable look and feel. Together they provide an elegant, yet easy-to-use solution to the problems of the AWT. More than anything else, it is these two features that define the essence of Swing. Each is examined here.

Swing Components Are Lightweight

With very few exceptions, Swing components are lightweight. This means that they are written entirely in Java and do not map directly to platform-specific peers. Thus, lightweight components are more efficient and more flexible. Furthermore, because lightweight components do not translate into native peers, the look and feel of each component is determined by Swing, not by the underlying operating system. As a result, each component will work in a consistent manner across all platforms.
Swing Supports a Pluggable Look and Feel

Swing supports a pluggable look and feel (PLAF). Because each Swing component is rendered by Java code rather than by native peers, the look and feel of a component is under the control of Swing. This fact means that it is possible to separate the look and feel of a component from the logic of the component, and this is what Swing does. Separating out the look and feel provides a significant advantage: it becomes possible to change the way that a component is rendered without affecting any of its other aspects. In other words, it is possible to “plug in” a new look and feel for any given component without creating any side effects in the code that uses that component. Moreover, it becomes possible to define entire sets of look-and-feels that represent different GUI styles. To use a specific style, its look and feel is simply “plugged in.” Once this is done, all components are automatically rendered using that style.

Pluggable look-and-feels offer several important advantages. It is possible to define a look and feel that is consistent across all platforms. Conversely, it is possible to create a look and feel that acts like a specific platform. For example, if you know that an application will be running only in a Windows environment, it is possible to specify the Windows look and feel. It is also possible to design a custom look and feel. Finally, the look and feel can be changed dynamically at run time.

Java provides look-and-feels, such as metal and Nimbus, that are available to all Swing users. The metal look and feel is also called the Java look and feel. It is platform-independent and available in all Java execution environments. It is also the default look and feel. Windows environments also have access to the Windows look and feel. This book uses the default Java look and feel (metal) because it is platform independent.

The MVC Connection

In general, a visual component is a composite of three distinct aspects:

- The way that the component looks when rendered on the screen
- The way that the component reacts to the user
- The state information associated with the component

No matter what architecture is used to implement a component, it must implicitly contain these three parts. Over the years, one component architecture has proven itself to be exceptionally effective: Model-View-Controller, or MVC for short.

The MVC architecture is successful because each piece of the design corresponds to an aspect of a component. In MVC terminology, the model corresponds to the
state information associated with the component. For example, in the case of a check box, the model contains a field that indicates if the box is checked or unchecked. The view determines how the component is displayed on the screen, including any aspects of the view that are affected by the current state of the model. The controller determines how the component reacts to the user. For example, when the user clicks a check box, the controller reacts by changing the model to reflect the user’s choice (checked or unchecked). This then results in the view being updated. By separating a component into a model, a view, and a controller, the specific implementation of each can be changed without affecting the other two. For instance, different view implementations can render the same component in different ways without affecting the model or the controller.

Although the MVC architecture and the principles behind it are conceptually sound, the high level of separation between the view and the controller is not beneficial for Swing components. Instead, Swing uses a modified version of MVC that combines the view and the controller into a single logical entity called the UI delegate. For this reason, Swing’s approach is called either the Model-Delegate architecture or the Separable Model architecture. Therefore, although Swing’s component architecture is based on MVC, it does not use a classical implementation of it.

Swing’s pluggable look and feel is made possible by its Model-Delegate architecture. Because the view (look) and controller (feel) are separate from the model, the look and feel can be changed without affecting how the component is used within a program. Conversely, it is possible to customize the model without affecting the way that the component appears on the screen or responds to user input.

To support the Model-Delegate architecture, most Swing components contain two objects. The first represents the model. The second represents the UI delegate. Models are defined by interfaces. For example, the model for a button is defined by the ButtonModel interface. UI delegates are classes that inherit ComponentUI. For example, the UI delegate for a button is ButtonUI. Normally, your programs will not interact directly with the UI delegate.

Components and Containers

A Swing GUI consists of two key items: components and containers. However, this distinction is mostly conceptual because all containers are also components. The difference between the two is found in their intended purpose: As the term is commonly used, a component is an independent visual control, such as a push button or slider. A container holds a group of components. Thus, a container is a special type of component that is designed to hold other components. Furthermore, in order
for a component to be displayed, it must be held within a container. Thus, all Swing GUIs will have at least one container. Because containers are components, a container can also hold other containers. This enables Swing to define what is called a containment hierarchy, at the top of which must be a top-level container.

Let’s look a bit more closely at components and containers.

## Components

In general, Swing components are derived from the `JComponent` class. (The only exceptions to this are the four top-level containers, described in the next section.) `JComponent` provides the functionality that is common to all components. For example, `JComponent` supports the pluggable look and feel. `JComponent` inherits the AWT classes `Container` and `Component`. Thus, a Swing component is built on and compatible with an AWT component.

All of Swing’s components are represented by classes defined within the package `javax.swing`. The following table shows the class names for Swing components (including those used as containers).

<table>
<thead>
<tr>
<th>JApplet</th>
<th>JButton</th>
<th>JCheckBox</th>
<th>JCheckBoxMenuItem</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Deprecated)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JColorChooser</td>
<td>JComboBox</td>
<td>JComponent</td>
<td>JDesktopPane</td>
</tr>
<tr>
<td>JDiallog</td>
<td>JEditorPane</td>
<td>JFileChooser</td>
<td>JFormattedTextField</td>
</tr>
<tr>
<td>JFrame</td>
<td>JInternalFrame</td>
<td>JLabel</td>
<td>JLayer</td>
</tr>
<tr>
<td>JLayeredPane</td>
<td>JList</td>
<td>JMenu</td>
<td>JMenuBar</td>
</tr>
<tr>
<td>JMenuItem</td>
<td>JOptionPane</td>
<td>JPanel</td>
<td>JPasswordField</td>
</tr>
<tr>
<td>JPopupMenu</td>
<td>JProgressBar</td>
<td>JRadioButton</td>
<td>JRadioButtonMenuItem</td>
</tr>
<tr>
<td>JRootPane</td>
<td>JScrollPane</td>
<td>JScrollPane</td>
<td>JSeparator</td>
</tr>
<tr>
<td>JSlider</td>
<td>JSpinner</td>
<td>JSplitPane</td>
<td>JTabbedPane</td>
</tr>
<tr>
<td>JTable</td>
<td>JTextArea</td>
<td>JTextField</td>
<td>JTextPane</td>
</tr>
<tr>
<td>JToggleButton</td>
<td>JToolBar</td>
<td>JToolBar</td>
<td>JTree</td>
</tr>
<tr>
<td>JViewport</td>
<td>JWindow</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notice that all component classes begin with the letter J. For example, the class for a label is `JLabel`; the class for a push button is `JButton`; and the class for a scrollbar is `JScrollBar`.
Containers

Swing defines two types of containers. The first are top-level containers: JFrame, JApplet, JWindow, and JDialog. These containers do not inherit JComponent. They do, however, inherit the AWT classes Component and Container. Unlike Swing’s other components, which are lightweight, the top-level containers are heavyweight. This makes the top-level containers a special case in the Swing component library.

As the name implies, a top-level container must be at the top of a containment hierarchy. A top-level container is not contained within any other container. Furthermore, every containment hierarchy must begin with a top-level container. The one most commonly used for applications is JFrame. The one used for applets is JApplet. As explained in Chapter 1, beginning with JDK 9 applets have been deprecated and are not recommended for new code.

The second type of containers supported by Swing are lightweight containers. Lightweight containers do inherit JComponent. An example of a lightweight container is JPanel, which is a general-purpose container. Lightweight containers are often used to organize and manage groups of related components because a lightweight container can be contained within another container. Thus, you can use lightweight containers such as JPanel to create subgroups of related controls that are contained within an outer container.

The Top-Level Container Panes

Each top-level container defines a set of panes. At the top of the hierarchy is an instance of JRootPane. JRootPane is a lightweight container whose purpose is to manage the other panes. It also helps manage the optional menu bar. The panes that comprise the root pane are called the glass pane, the content pane, and the layered pane.

The glass pane is the top-level pane. It sits above and completely covers all other panes. By default, it is a transparent instance of JPanel. The glass pane enables you to manage mouse events that affect the entire container (rather than an individual control) or to paint over any other component, for example. In most cases, you won’t need to use the glass pane directly, but it is there if you need it.

The layered pane is an instance of JLayeredPane. The layered pane allows components to be given a depth value. This value determines which component overlays another. (Thus, the layered pane lets you specify a Z-order for a component, although this is not something that you will usually need to do.) The layered pane holds the content pane and the (optional) menu bar.
Although the glass pane and the layered panes are integral to the operation of a top-level container and serve important purposes, much of what they provide occurs behind the scene. The pane with which your application will interact the most is the content pane, because this is the pane to which you will add visual components. In other words, when you add a component, such as a button, to a top-level container, you will add it to the content pane. By default, the content pane is an opaque instance of JPanel.

The Swing Packages

Swing is a very large subsystem and makes use of many packages. At the time of this writing, these are the packages defined by Swing.

<table>
<thead>
<tr>
<th>javax.swing</th>
<th>javax.swing.plaf.basic</th>
<th>javax.swing.text</th>
</tr>
</thead>
<tbody>
<tr>
<td>javax.swing.border</td>
<td>javax.swing.plaf.metal</td>
<td>javax.swing.text.html</td>
</tr>
<tr>
<td>javax.swing.colorchooser</td>
<td>javax.swing.plaf.multi</td>
<td>javax.swing.text.html.html.parser</td>
</tr>
<tr>
<td>javax.swing.event</td>
<td>javax.swing.plaf.nimbus</td>
<td>javax.swing.text.rtf</td>
</tr>
<tr>
<td>javax.swing.filechooser</td>
<td>javax.swing.plaf.synth</td>
<td>javax.swing.tree</td>
</tr>
<tr>
<td>javax.swing.plaf</td>
<td>javax.swing.table</td>
<td>javax.swing.undo</td>
</tr>
</tbody>
</table>

Beginning the JDK 9, the Swing packages are part of the java.desktop module. The main package isjavax.swing. This package must be imported into any program that uses Swing. It contains the classes that implement the basic Swing components, such as push buttons, labels, and check boxes.

A Simple Swing Application

Swing programs differ from both the console-based programs and the AWT-based programs shown earlier in this book. For example, they use a different set of components and a different container hierarchy than does the AWT. Swing programs also have special requirements that relate to threading. The best way to understand the structure of a Swing program is to work through an example. Before we begin, it is necessary to point out that there are two types of Java programs in which Swing was typically used. The first is a desktop application, and that is the type of Swing program described here. The second is the applet. Because applets are now deprecated and not recommended for new code, they are not discussed in this chapter. Instead, a brief overview of applets, including Swing applets, is given in Appendix D, primarily for the benefit of programmers working with legacy code.
Although quite short, the following program shows one way to write a Swing application. In the process, it demonstrates several key features of Swing. It uses two Swing components: JFrame and JLabel. JFrame is the top-level container that is commonly used for Swing applications. JLabel is the Swing component that creates a label, which is a component that displays information. The label is Swing’s simplest component because it is passive. That is, a label does not respond to user input. It just displays output. The program uses a JFrame container to hold an instance of a JLabel. The label displays a short text message.
// A simple Swing application.

import javax.swing.*;

class SwingDemo {
    
    SwingDemo() {

        // Create a new JFrame container.
        JFrame jfrm = new JFrame("A Simple Swing Application");

        // Give the frame an initial size.
        jfrm.setSize(275, 100);

        // Terminate the program when the user closes the application.
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

        // Create a text-based label.
        JLabel jlab = new JLabel(" Swing means powerful GUIs.");

        // Add the label to the content pane.
        jfrm.add(jlab);

        // Display the frame.
        jfrm.setVisible(true);
    }

    public static void main(String args[]) {
        // Create the frame on the event dispatching thread.
        SwingUtilities.invokeLater(new Runnable() {
            public void run() {
                new SwingDemo();
            }
        });
    }
}

Swing programs are compiled and run in the same way as other Java applications. Thus, to compile this program, you can use this command line:

javac SwingDemo.java

To run the program, use this command line:
When the program is run, it will produce a window similar to that shown in Figure 31-1.

![Figure 31-1](image.png)

The window produced by the **SwingDemo** program

Because the **SwingDemo** program illustrates several core Swing concepts, we will examine it carefully, line by line. The program begins by importing **javax.swing**. As mentioned, this package contains the components and models defined by Swing. For example, **javax.swing** defines classes that implement labels, buttons, text controls, and menus. It will be included in all programs that use Swing.

Next, the program declares the **SwingDemo** class and a constructor for that class. The constructor is where most of the action of the program occurs. It begins by creating a **JFrame**, using this line of code:

```java
JFrame jfrm = new JFrame("A Simple Swing Application");
```

This creates a container called **jfrm** that defines a rectangular window complete with a title bar; close, minimize, maximize, and restore buttons; and a system menu. Thus, it creates a standard, top-level window. The title of the window is passed to the constructor.

Next, the window is sized using this statement:

```java
jfrm.setSize(275, 100);
```

The **setSize( )** method (which is inherited by **JFrame** from the AWT class **Component**) sets the dimensions of the window, which are specified in pixels. Its general form is shown here:

```java
void setSize(int width, int height)
```

In this example, the width of the window is set to 275 and the height is set to 100.

By default, when a top-level window is closed (such as when the user clicks the close box), the window is removed from the screen, but the application is not terminated. While this default behavior is useful in some situations, it is not what is needed for most applications. Instead, you will usually want the entire application to
terminate when its top-level window is closed. There are a couple of ways to achieve this. The easiest way is to call `setDefaultCloseOperation()`, as the program does:

```java
jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
```

After this call executes, closing the window causes the entire application to terminate. The general form of `setDefaultCloseOperation()` is shown here:

```java
void setDefaultCloseOperation(int what)
```

The value passed in `what` determines what happens when the window is closed. There are several other options in addition to `JFrame.EXIT_ON_CLOSE`. They are shown here:

- `DISPOSE_ON_CLOSE`
- `HIDE_ON_CLOSE`
- `DO_NOTHING_ON_CLOSE`

Their names reflect their actions. These constants are declared in `WindowConstants`, which is an interface declared in `javax.swing` that is implemented by `JFrame`.

The next line of code creates a Swing `JLabel` component:

```java
JLabel jlab = new JLabel(" Swing means powerful GUIs.");
```

`JLabel` is the simplest and easiest-to-use component because it does not accept user input. It simply displays information, which can consist of text, an icon, or a combination of the two. The label created by the program contains only text, which is passed to its constructor.

The next line of code adds the label to the content pane of the frame:

```java
jfrm.add(jlab);
```

As explained earlier, all top-level containers have a content pane in which components are stored. Thus, to add a component to a frame, you must add it to the frame’s content pane. This is accomplished by calling `add()` on the `JFrame` reference (`jfrm` in this case). The general form of `add()` is shown here:

```java
Component add(Component comp)
```

The `add()` method is inherited by `JFrame` from the AWT class `Container`. By default, the content pane associated with a `JFrame` uses border layout. The
version of \texttt{add()} just shown adds the label to the center location. Other versions of \texttt{add()} enable you to specify one of the border regions. When a component is added to the center, its size is adjusted automatically to fit the size of the center.

Before continuing, an important historical point needs to be made. Prior to JDK 5, when adding a component to the content pane, you could not invoke the \texttt{add()} method directly on a \texttt{JFrame} instance. Instead, you needed to call \texttt{add()} on the content pane of the \texttt{JFrame} object. The content pane can be obtained by calling \texttt{getContentPane()} on a \texttt{JFrame} instance. The \texttt{getContentPane()} method is shown here:

\begin{verbatim}
Container getContentPane()
\end{verbatim}

It returns a \texttt{Container} reference to the content pane. The \texttt{add()} method was then called on that reference to add a component to a content pane. Thus, in the past, you had to use the following statement to add \texttt{jlab} to \texttt{jfrm}:

\begin{verbatim}
jfrm.getContentPane().add(jlab); // old-style
\end{verbatim}

Here, \texttt{getContentPane()} first obtains a reference to content pane, and then \texttt{add()} adds the component to the container linked to this pane. This same procedure was also required to invoke \texttt{remove()} to remove a component and \texttt{setLayout()} to set the layout manager for the content pane. This is why you will see explicit calls to \texttt{getContentPane()} frequently throughout pre-5.0 legacy code. Today, the use of \texttt{getContentPane()} is no longer necessary. You can simply call \texttt{add()}, \texttt{remove()}, and \texttt{setLayout()} directly on \texttt{JFrame} because these methods have been changed so that they operate on the content pane automatically.

The last statement in the \texttt{SwingDemo} constructor causes the window to become visible:

\begin{verbatim}
jfrm.setVisible(true);
\end{verbatim}

The \texttt{setVisible()} method is inherited from the AWT \texttt{Component} class. If its argument is \texttt{true}, the window will be displayed. Otherwise, it will be hidden. By default, a \texttt{JFrame} is invisible, so \texttt{setVisible(true)} must be called to show it.

Inside \texttt{main()}, a \texttt{SwingDemo} object is created, which causes the window and the label to be displayed. Notice that the \texttt{SwingDemo} constructor is invoked using these lines of code:
This sequence causes a **SwingDemo** object to be created on the *event dispatching thread* rather than on the main thread of the application. Here’s why. In general, Swing programs are event-driven. For example, when a user interacts with a component, an event is generated. An event is passed to the application by calling an event handler defined by the application. However, the handler is executed on the event dispatching thread provided by Swing and not on the main thread of the application. Thus, although event handlers are defined by your program, they are called on a thread that was not created by your program.

To avoid problems (including the potential for deadlock), all Swing GUI components must be created and updated from the event dispatching thread, not the main thread of the application. However, **main( )** is executed on the main thread. Thus, **main( )** cannot directly instantiate a **SwingDemo** object. Instead, it must create a **Runnable** object that executes on the event dispatching thread and have this object create the GUI.

To enable the GUI code to be created on the event dispatching thread, you must use one of two methods that are defined by the **SwingUtilities** class. These methods are **invokeLater( )** and **invokeAndWait( )**. They are shown here:

```java
static void invokeLater(Runnable obj)
static void invokeAndWait(Runnable obj) throws InterruptedException,
                             InvocationTargetException
```

Here, **obj** is a **Runnable** object that will have its **run( )** method called by the event dispatching thread. The difference between the two methods is that **invokeLater( )** returns immediately, but **invokeAndWait( )** waits until **obj.run( )** returns. You can use one of these methods to call a method that constructs the GUI for your Swing application, or whenever you need to modify the state of the GUI from code not executed by the event dispatching thread. You will normally want to use **invokeLater( )**, as the preceding program does. However, when the initial GUI for an applet is constructed, **invokeAndWait( )** is required. Thus, you will see its use in legacy applet code.

**Event Handling**
The preceding example showed the basic form of a Swing program, but it left out one important part: event handling. Because `JLabel` does not take input from the user, it does not generate events, so no event handling was needed. However, the other Swing components do respond to user input and the events generated by those interactions need to be handled. Events can also be generated in ways not directly related to user input. For example, an event is generated when a timer goes off. Whatever the case, event handling is a large part of any Swing-based application.

The event handling mechanism used by Swing is the same as that used by the AWT. This approach is called the *delegation event model*, and it is described in *Chapter 24*. In many cases, Swing uses the same events as does the AWT, and these events are packaged in `java.awt.event`. Events specific to Swing are stored in `javax.swing.event`.

Although events are handled in Swing in the same way as they are with the AWT, it is still useful to work through a simple example. The following program handles the event generated by a Swing push button. Sample output is shown in Figure 31-2.

![An Event Example](attachment:An_Event_Example.png)

**Figure 31-2** Output from the `EventDemo` program
// Handle an event in a Swing program.

import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

class EventDemo {

    JLabel jlab;

    EventDemo() {

        // Create a new JFrame container.
        JFrame jfrm = new JFrame("An Event Example");

        // Specify FlowLayout for the layout manager.
        jfrm.setLayout(new FlowLayout());

        // Give the frame an initial size.
        jfrm.setSize(220, 90);

        // Terminate the program when the user closes the application.
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

        // Make two buttons.
        JButton jbtnAlpha = new JButton("Alpha");
        JButton jbtnBeta = new JButton("Beta");

        // Add action listener for Alpha.
        jbtnAlpha.addActionListener(new ActionListener() {
            public void actionPerformed(ActionEvent ae) {
                jlab.setText("Alpha was pressed.");
            }
        });
    }
}
First, notice that the program now imports both the `java.awt` and `java.awt.event` packages. The `java.awt` package is needed because it contains the `FlowLayout` class, which supports the standard flow layout manager used to lay out components in a frame. (See Chapter 26 for coverage of layout managers.) The `java.awt.event` package is needed because it defines the `ActionListener` interface and the `ActionEvent` class.

The `EventDemo` constructor begins by creating a `JFrame` called `jfrm`. It then sets the layout manager for the content pane of `jfrm` to `FlowLayout`. By default, the content pane uses `BorderLayout` as its layout manager. However, for this example, `FlowLayout` is more convenient.

After setting the size and default close operation, `EventDemo()` creates two push buttons, as shown here:
The first button will contain the text "Alpha" and the second will contain the text "Beta". Swing push buttons are instances of JButton. JButton supplies several constructors. The one used here is

JButton(String msg)

The msg parameter specifies the string that will be displayed inside the button.

When a push button is pressed, it generates an ActionEvent. Thus, JButton provides the addActionListener() method, which is used to add an action listener. (JButton also provides removeActionListener() to remove a listener, but this method is not used by the program.) As explained in Chapter 24, the ActionListener interface defines only one method: actionPerformed(). It is shown again here for your convenience:

void actionPerformed(ActionEvent ae)

This method is called when a button is pressed. In other words, it is the event handler that is called when a button press event has occurred.

Next, event listeners for the button’s action events are added by the code shown here:

```java
// Add action listener for Alpha.
btnAlpha.addActionListener(new ActionListener() {
    public void actionPerformed(ActionEvent ae) {
        jlab.setText("Alpha was pressed.");
    }
});

// Add action listener for Beta.
btnBeta.addActionListener(new ActionListener() {
    public void actionPerformed(ActionEvent ae) {
        jlab.setText("Beta was pressed.");
    }
});
```

Here, anonymous inner classes are used to provide the event handlers for the two buttons. Each time a button is pressed, the string displayed in jlab is changed to reflect which button was pressed.

Beginning with JDK 8, lambda expressions can also be used to implement some
types of event handlers. For example, the event handler for the Alpha button could be written like this:

```java
jbtnAlpha.addActionListener((ae) -> jlab.setText("Alpha was pressed."));```

As you can see, this code is shorter. Of course, the approach you choose will be determined by the situation and your own preferences.

Next, the buttons are added to the content pane of `jfrm`:

```java
jfrm.add(jbtnAlpha);
jfrm.add(jbtnBeta);
```

Finally, `jlab` is added to the content pane and window is made visible. When you run the program, each time you press a button, a message is displayed in the label that indicates which button was pressed.

One last point: Remember that all event handlers, such as `actionPerformed()`, are called on the event dispatching thread. Therefore, an event handler must return quickly in order to avoid slowing down the application. If your application needs to do something time consuming as the result of an event, it must use a separate thread.

**Painting in Swing**

Although the Swing component set is quite powerful, you are not limited to using it because Swing also lets you write directly into the display area of a frame, panel, or one of Swing’s other components, such as `JLabel`. Although many (perhaps most) uses of Swing will not involve drawing directly to the surface of a component, it is available for those applications that need this capability. To write output directly to the surface of a component, you will use one or more drawing methods defined by the AWT, such as `drawLine()` or `drawRect()`. Thus, most of the techniques and methods described in Chapter 25 also apply to Swing. However, there are also some very important differences, and the process is discussed in detail in this section.

**Painting Fundamentals**

Swing’s approach to painting is built on the original AWT-based mechanism, but Swing’s implementation offers more finely grained control. Before examining the specifics of Swing-based painting, it is useful to review the AWT-based mechanism that underlies it.

The AWT class `Component` defines a method called `paint()` that is used to draw output directly to the surface of a component. For the most part, `paint()` is not called by your program. (In fact, only in the most unusual cases should it ever be called by
your program.) Rather, paint( ) is called by the run-time system whenever a component must be rendered. This situation can occur for several reasons. For example, the window in which the component is displayed can be overwritten by another window and then uncovered. Or, the window might be minimized and then restored. The paint( ) method is also called when a program begins running. When writing AWT-based code, an application will override paint( ) when it needs to write output directly to the surface of the component.

Because JComponent inherits Component, all Swing’s lightweight components inherit the paint( ) method. However, you will not override it to paint directly to the surface of a component. The reason is that Swing uses a bit more sophisticated approach to painting that involves three distinct methods: paintComponent( ), paintBorder( ), and paintChildren( ). These methods paint the indicated portion of a component and divide the painting process into its three distinct, logical actions. In a lightweight component, the original AWT method paint( ) simply executes calls to these methods, in the order just shown.

To paint to the surface of a Swing component, you will create a subclass of the component and then override its paintComponent( ) method. This is the method that paints the interior of the component. You will not normally override the other two painting methods. When overriding paintComponent( ), the first thing you must do is call super.paintComponent( ), so that the superclass portion of the painting process takes place. (The only time this is not required is when you are taking complete, manual control over how a component is displayed.) After that, write the output that you want to display. The paintComponent( ) method is shown here:

```java
protected void paintComponent(Graphics g)
```

The parameter g is the graphics context to which output is written.

To cause a component to be painted under program control, call repaint( ). It works in Swing just as it does for the AWT. The repaint( ) method is defined by Component. Calling it causes the system to call paint( ) as soon as it is possible to do so. Because painting is a time-consuming operation, this mechanism allows the run-time system to defer painting momentarily until some higher-priority task has completed, for example. Of course, in Swing the call to paint( ) results in a call to paintComponent( ). Therefore, to output to the surface of a component, your program will store the output until paintComponent( ) is called. Inside the overridden paintComponent( ), you will draw the stored output.

**Compute the Paintable Area**
When drawing to the surface of a component, you must be careful to restrict your output to the area that is inside the border. Although Swing automatically clips any output that will exceed the boundaries of a component, it is still possible to paint into the border, which will then get overwritten when the border is drawn. To avoid this, you must compute the *paintable area* of the component. This is the area defined by the current size of the component minus the space used by the border. Therefore, before you paint to a component, you must obtain the width of the border and then adjust your drawing accordingly.

To obtain the border width, call `getInsets()`, shown here:

```
Insets getInsets()
```

This method is defined by `Container` and overridden by `JComponent`. It returns an `Insets` object that contains the dimensions of the border. The inset values can be obtained by using these fields:

```
int top;
int bottom;
int left;
int right;
```

These values are then used to compute the drawing area given the width and the height of the component. You can obtain the width and height of the component by calling `getWidth()` and `getHeight()` on the component. They are shown here:

```
int getWidth()
int getHeight()
```

By subtracting the value of the insets, you can compute the usable width and height of the component.

**A Paint Example**

Here is a program that puts into action the preceding discussion. It creates a class called `PaintPanel` that extends `JPanel`. The program then uses an object of that class to display lines whose endpoints have been generated randomly. Sample output is shown in Figure 31-3.
Figure 31-3  Sample output from the **PaintPanel** program

```java
// Paint lines to a panel.
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;
import java.util.*;

// This class extends JPanel. It overrides
// the paintComponent() method so that random
// lines are plotted in the panel.
class PaintPanel extends JPanel {
    Insets ins; // holds the panel’s insets
    Random rand; // used to generate random numbers

    // Construct a panel.
    PaintPanel() {
        // Put a border around the panel.
        borderColor = BorderLayout(Color.RED, 5);

        rand = new Random();
    }

    // Override the paintComponent() method.
    protected void paintComponent(Graphics g) {
        // Always call the superclass method first.
        super.paintComponent(g);

        int x, y, x2, y2;
    }
```
// Get the height and width of the component.
int height = getHeight();
int width = getWidth();

// Get the insets.
ins = getInsets();

// Draw ten lines whose endpoints are randomly generated.
for(int i=0; i < 10; i++) {
    // Obtain random coordinates that define
    // the endpoints of each line.
    x = rand.nextInt(width-ins.left);
    y = rand.nextInt(height-ins.bottom);
    x2 = rand.nextInt(width-ins.left);
    y2 = rand.nextInt(height-ins.bottom);

    // Draw the line.
g.drawLine(x, y, x2, y2);
}

// Demonstrate painting directly onto a panel.
class PaintDemo {
    JLabel jlab;
    PaintPanel pp;

    PaintDemo() {
        // Create a new JFrame container.
        JFrame jfrm = new JFrame("Paint Demo");

        // Give the frame an initial size.
jfrm.setSize(200, 150);

        // Terminate the program when the user closes the application.
jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
    }
}
Let’s examine this program closely. The `PaintPanel` class extends `JPanel`. `JPanel` is one of Swing’s lightweight containers, which means that it is a component that can be added to the content pane of a `JFrame`. To handle painting, `PaintPanel` overrides the `paintComponent()` method. This enables `PaintPanel` to write directly to the surface of the component when painting takes place. The size of the panel is not specified because the program uses the default border layout and the panel is added to the center. This results in the panel being sized to fill the center. If you change the size of the window, the size of the panel will be adjusted accordingly.

Notice that the constructor also specifies a 5-pixel wide, red border. This is accomplished by setting the border by using the `setBorder()` method, shown here:

```java
void setBorder(Border border)
```

`Border` is the Swing interface that encapsulates a border. You can obtain a border by calling one of the factory methods defined by the `BorderFactory` class. The one used in the program is `createLineBorder()`, which creates a simple line border. It is shown here:

```java
static Border createLineBorder(Color clr, int width)
```

Here, `clr` specifies the color of the border and `width` specifies its width in pixels.
Inside the override of `paintComponent()`, notice that it first calls `super.paintComponent()`. As explained, this is necessary to ensure that the component is properly drawn. Next, the width and height of the panel are obtained along with the insets. These values are used to ensure the lines lie within the drawing area of the panel. The drawing area is the overall width and height of a component less the border width. The computations are designed to work with differently sized `PaintPanel`S and borders. To prove this, try changing the size of the window. The lines will still all lie within the borders of the panel.

The `PaintDemo` class creates a `PaintPanel` and then adds the panel to the content pane. When the application is first displayed, the overridden `paintComponent()` method is called, and the lines are drawn. Each time you resize or hide and restore the window, a new set of lines are drawn. In all cases, the lines fall within the paintable area.
Exploring Swing

The previous chapter described several of the core concepts relating to Swing and showed the general form of a Swing application. This chapter continues the discussion of Swing by presenting an overview of several Swing components, such as buttons, check boxes, trees, and tables. The Swing components provide rich functionality and allow a high level of customization. Because of space limitations, it is not possible to describe all of their features and attributes. Rather, the purpose of this overview is to give you a feel for the capabilities of the Swing component set.

The Swing component classes described in this chapter are shown here:

<table>
<thead>
<tr>
<th>JButton</th>
<th>JCheckBox</th>
<th>JComboBox</th>
<th>JLabel</th>
</tr>
</thead>
<tbody>
<tr>
<td>JList</td>
<td>JRadioButton</td>
<td>JScrollPane</td>
<td>JTabbedPane</td>
</tr>
<tr>
<td>JTable</td>
<td>JTextField</td>
<td>JToggleButton</td>
<td>JTree</td>
</tr>
</tbody>
</table>

These components are all lightweight, which means that they are all derived from JComponent.

Also discussed is the ButtonGroup class, which encapsulates a mutually exclusive set of Swing buttons, and ImageIcon, which encapsulates a graphics image. Both are defined by Swing and packaged in javax.swing.

JLabel and ImageIcon

JLabel is Swing’s easiest-to-use component. It creates a label and was introduced in the preceding chapter. Here, we will look at JLabel a bit more closely. JLabel can be used to display text and/or an icon. It is a passive component in that it does not respond to user input. JLabel defines several constructors. Here are three of them:

- JLabel(Icon icon)
- JLabel(String str)
- JLabel(String str, Icon icon, int align)

Here, str and icon are the text and icon used for the label. The align argument specifies the horizontal alignment of the text and/or icon within the dimensions of the label. It must be one of the following values: LEFT, RIGHT, CENTER,
LEADING, or TRAILING. These constants are defined in the SwingConstants interface, along with several others used by the Swing classes.

Notice that icons are specified by objects of type Icon, which is an interface defined by Swing. The easiest way to obtain an icon is to use the ImageIcon class. ImageIcon implements Icon and encapsulates an image. Thus, an object of type ImageIcon can be passed as an argument to the Icon parameter of JLabel’s constructor. There are several ways to provide the image, including reading it from a file or downloading it from a URL. Here is the ImageIcon constructor used by the example in this section:

    ImageIcon(String filename)

It obtains the image in the file named filename.

The icon and text associated with the label can be obtained by the following methods:

    Icon getIcon()
    String getText()

The icon and text associated with a label can be set by these methods:

    void setIcon(Icon icon)
    void setText(String str)

Here, icon and str are the icon and text, respectively. Therefore, using setText() it is possible to change the text inside a label during program execution.

The following program illustrates how to create and display a label containing both an icon and a string. It begins by creating an ImageIcon object for the file hourglass.png, which depicts an hourglass. This is used as the second argument to the JLabel constructor. The first and last arguments for the JLabel constructor are the label text and the alignment. Finally, the label is added to the content pane.
import java.awt.*;
import javax.swing.*;

public class JLabelDemo {

    public JLabelDemo() {

        // Set up the JFrame.
        JFrame jfrm = new JFrame("JLabelDemo");
        jfrm.setLayout(new FlowLayout());
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        jfrm.setSize(260, 210);

        // Create an icon.
        ImageIcon ii = new ImageIcon("hourglass.png");

        // Create a label.
        JLabel jl = new JLabel("Hourglass", ii, JLabel.CENTER);

        // Add the label to the content pane.
        jfrm.add(jl);

        // Display the frame.
        jfrm.setVisible(true);
    }

    public static void main(String[] args) {
        // Create the frame on the event dispatching thread.

        SwingUtilities.invokeLater(
            new Runnable() {
                public void run() {
                    new JLabelDemo();
                }
            });
    }
}

Output from the label example is shown here:
JTextField

JTextField is the simplest Swing text component. It is also probably its most widely used text component. JTextField allows you to edit one line of text. It is derived from JTextComponent, which provides the basic functionality common to Swing text components. JTextField uses the Document interface for its model. Three of JTextField’s constructors are shown here:

JTextField(int cols)
JTextField(String str, int cols)
JTextField(String str)

Here, str is the string to be initially presented, and cols is the number of columns in the text field. If no string is specified, the text field is initially empty. If the number of columns is not specified, the text field is sized to fit the specified string.

JTextField generates events in response to user interaction. For example, an ActionEvent is fired when the user presses enter. A CaretEvent is fired each time the caret (i.e., the cursor) changes position. (CaretEvent is packaged in javax.swing.event.) Other events are also possible. In many cases, your program will not need to handle these events. Instead, you will simply obtain the string currently in the text field when it is needed. To obtain the text currently in the text field, call getText().

The following example illustrates JTextField. It creates a JTextField and adds it to the content pane. When the user presses enter, an action event is generated. This is handled by displaying the text in a label.
// Demonstrate JTextField.
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

public class JTextFieldDemo {

    public JTextFieldDemo() {

        // Set up the JFrame.
        JFrame jfrm = new JFrame("JTextFieldDemo");
        jfrm.setLayout(new FlowLayout());
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        jfrm.setSize(260, 120);

        // Add a text field to content pane.
        JTextField jtf = new JTextField(15);
        jfrm.add(jtf);

        // Add a label.
        JLabel jlab = new JLabel();
        jfrm.add(jlab);

        // Handle action events.
        jtf.addActionListener(new ActionListener() {
            public void actionPerformed(ActionEvent ae) {
                // Show text when user presses ENTER.
                jlab.setText(jtf.getText());
            }
        });

        // Display the frame.
        jfrm.setVisible(true);
    }

    public static void main(String[] args) {
        // Create the frame on the event dispatching thread.

        SwingUtilities.invokeLater( 
            new Runnable() {
                public void run() {
                    new JTextFieldDemo();
                }
            } 
        );
    }
}
The Swing Buttons

Swing defines four types of buttons: JButton, JToggleButton, JCheckBox, and JRadioButton. All are subclasses of the AbstractButton class, which extends JComponent. Thus, all buttons share a set of common traits.

AbstractButton contains many methods that allow you to control the behavior of buttons. For example, you can define different icons that are displayed for the button when it is disabled, pressed, or selected. Another icon can be used as a rollover icon, which is displayed when the mouse is positioned over a button. The following methods set these icons:

void setDisabledIcon(Icon di)
void setPressedIcon(Icon pi)
void setSelectedIcon(Icon si)
void setRolloverIcon(Icon ri)

Here, di, pi, si, and ri are the icons to be used for the indicated purpose.

The text associated with a button can be read and written via the following methods:

String getText( )
void setText(String str)

Here, str is the text to be associated with the button.

The model used by all buttons is defined by the ButtonModel interface. A button generates an action event when it is pressed. Other events are possible. Each of the concrete button classes is examined next.
**JButton**

The **JButton** class provides the functionality of a push button. You have already seen a simple form of it in the preceding chapter. **JButton** allows an icon, a string, or both to be associated with the push button. Three of its constructors are shown here:

- `JButton(Icon icon)`
- `JButton(String str)`
- `JButton(String str, Icon icon)`

Here, `str` and `icon` are the string and icon used for the button.

When the button is pressed, an **ActionEvent** is generated. Using the **ActionEvent** object passed to the `actionPerformed()` method of the registered **ActionListener**, you can obtain the *action command* string associated with the button. By default, this is the string displayed inside the button. However, you can set the action command by calling `setActionCommand()` on the button. You can obtain the action command by calling `getActionCommand()` on the event object. It is declared like this:

```java
String getActionCommand()
```

The action command identifies the button. Thus, when using two or more buttons within the same application, the action command gives you an easy way to determine which button was pressed.

In the preceding chapter, you saw an example of a text-based button. The following demonstrates an icon-based button. It displays four push buttons and a label. Each button displays an icon that represents a timepiece. When a button is pressed, the name of that timepiece is displayed in the label.
// Demonstrate an icon-based JButton.
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

public class JButtonDemo implements ActionListener {
    JLabel jlab;

    public JButtonDemo() {

        // Set up the JFrame.
        JFrame jfrm = new JFrame("JButtonDemo");
        jfrm.setLayout(new FlowLayout());
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        jfrm.setSize(500, 450);

        // Add buttons to content pane.
        ImageIcon hourglass = new ImageIcon("hourglass.png");
        JButton jb = new JButton(hourglass);
        jb.setActionCommand("Hourglass");
        jb.addActionListener(this);
        jfrm.add(jb);

        ImageIcon analog = new ImageIcon("analog.png");
        jb = new JButton(analog);
        jb.setActionCommand("Analog Clock");
        jb.addActionListener(this);
        jfrm.add(jb);

        ImageIcon digital = new ImageIcon("digital.png");
        jb = new JButton(digital);
        jb.setActionCommand("Digital Clock");
        jb.addActionListener(this);
        jfrm.add(jb);

        ImageIcon stopwatch = new ImageIcon("stopwatch.png");
        jb = new JButton(stopwatch);
        jb.setActionCommand("Stopwatch");
        jb.addActionListener(this);
        jfrm.add(jb);
// Create and add the label to content pane.
jlab = new JLabel("Choose a Timepiece");
jfrm.add(jlab);

// Display the frame.
jfrm.setVisible(true);

// Handle button events.
public void actionPerformed(ActionEvent ae) {
    jlab.setText("You selected " + ae.getActionCommand());
}

public static void main(String[] args) {
    // Create the frame on the event dispatching thread.
    SwingUtilities.invokeLater(
        new Runnable() {
            public void run() {
                new JButtonDemo();
            }
        }
    );
}

Output from the button example is shown here:
A useful variation on the push button is called a toggle button. A toggle button looks just like a push button, but it acts differently because it has two states: pushed and released. That is, when you press a toggle button, it stays pressed rather than popping back up as a regular push button does. When you press the toggle button a second time, it releases (pops up). Therefore, each time a toggle button is pushed, it toggles between its two states.

Toggle buttons are objects of the \texttt{JToggleButton} class. \texttt{JToggleButton} implements \texttt{AbstractButton}. In addition to creating standard toggle buttons, \texttt{JToggleButton} is a superclass for two other Swing components that also represent two-state controls. These are \texttt{JCheckBox} and \texttt{JRadioButton}, which are described later in this chapter. Thus, \texttt{JToggleButton} defines the basic functionality of all two-state components.

\texttt{JToggleButton} defines several constructors. The one used by the example in this section is shown here:

\begin{verbatim}
JToggleButton(String \textit{str})
\end{verbatim}

This creates a toggle button that contains the text passed in \textit{str}. By default, the button is in the off position. Other constructors enable you to create toggle buttons that contain images, or images and text.

\texttt{JToggleButton} uses a model defined by a nested class called \texttt{JToggleButton.Toggle-ButtonModel}. Normally, you won’t need to interact directly with the model to use a standard toggle button.

Like \texttt{JButton}, \texttt{JToggleButton} generates an action event each time it is pressed. Unlike \texttt{JButton}, however, \texttt{JToggleButton} also generates an item event. This event is used by those components that support the concept of selection. When a \texttt{JToggleButton} is pressed in, it is selected. When it is popped out, it is deselected.

To handle item events, you must implement the \texttt{ItemListener} interface. Recall from Chapter 24, that each time an item event is generated, it is passed to the \texttt{itemStateChanged(\ )} method defined by \texttt{ItemListener}. Inside \texttt{itemStateChanged(\ )}, the \texttt{getItem(\ )} method can be called on the \texttt{ItemEvent} object to obtain a reference to the \texttt{JToggleButton} instance that generated the event. It is shown here:

\begin{verbatim}
Object getItem(\ )
\end{verbatim}

A reference to the button is returned. You will need to cast this reference to \texttt{JToggleButton}.

The easiest way to determine a toggle button’s state is by calling the \texttt{isSelected(\ )}
method (inherited from AbstractButton) on the button that generated the event. It is shown here:

    boolean isSelected( )

It returns true if the button is selected and false otherwise.

Here is an example that uses a toggle button. Notice how the item listener works. It simply calls isSelected( ) to determine the button’s state.

    // Demonstrate JToggleButton.
    import java.awt.*;
    import java.awt.event.*;
    import javax.swing.*;

    public class JToggleButtonDemo { ```
    public JToggleButtonDemo() {
```
// Set up the JFrame.
JFrame jfrm = new JFrame("JToggleButtonDemo");
jfrm.setLayout(new FlowLayout());
jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
jfrm.setSize(200, 100);

// Create a label.
JLabel jlab = new JLabel("Button is off.");

// Make a toggle button.
JToggleButton jbtn = new JToggleButton("On/Off");

// Add an item listener for the toggle button.
jbtn.addItemListener(new ItemListener() {
    public void itemStateChanged(ItemEvent ie) {
        if(jbtn.isSelected())
            jlab.setText("Button is on.");
        else
            jlab.setText("Button is off.");
    }
});

// Add the toggle button and label to the content pane.
jfrm.add(jbtn);
jfrm.add(jlab);

// Display the frame.
jfrm.setVisible(true);
}

public static void main(String[] args) {
    // Create the frame on the event dispatching thread.
    SwingUtilities.invokeLater(
        new Runnable() {
            public void run() {
                new JToggleButtonDemo();
            }
        });
}
The output from the toggle button example is shown here:

![Image](image.png)

**Check Boxes**

The JCheckBox class provides the functionality of a check box. Its immediate superclass is JToggleButton, which provides support for two-state buttons, as just described. JCheckBox defines several constructors. The one used here is

```java
JCheckBox(String str)
```

It creates a check box that has the text specified by str as a label. Other constructors let you specify the initial selection state of the button and specify an icon.

When the user selects or deselects a check box, an ItemEvent is generated. You can obtain a reference to the JCheckBox that generated the event by calling `getItem()` on the ItemEvent passed to the `itemStateChanged()` method defined by ItemListener. The easiest way to determine the selected state of a check box is to call `isSelected()` on the JCheckBox instance.

The following example illustrates check boxes. It displays four check boxes and a label. When the user clicks a check box, an ItemEvent is generated. Inside the `itemStateChanged()` method, `getItem()` is called to obtain a reference to the JCheckBox object that generated the event. Next, a call to `isSelected()` determines if the box was selected or cleared. The `getText()` method gets the text for that check box and uses it to set the text inside the label.
// Demonstrate JCheckBox.
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

public class JCheckBoxDemo implements ItemListener {
    JLabel jlab;

    public JCheckBoxDemo() {

        // Set up the JFrame.
        JFrame jfrm = new JFrame("JCheckBoxDemo");
        jfrm.setLayout(new FlowLayout());
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        jfrm.setSize(250, 100);

        // Add check boxes to the content pane.
        JCheckBox cb = new JCheckBox("C");
        cb.addItemListener(this);
        jfrm.add(cb);

        cb = new JCheckBox("C++");
        cb.addItemListener(this);
        jfrm.add(cb);

        cb = new JCheckBox("Java");
        cb.addItemListener(this);
        jfrm.add(cb);
cb = new JCheckBox("Perl");
cb.addItemListener(this);
jfrm.add(cb);

// Create the label and add it to the content pane.
jlab = new JLabel("Select languages");
jfrm.add(jlab);

// Display the frame.
jfrm.setVisible(true);

// Handle item events for the check boxes.
public void itemStateChanged(ItemEvent ie) {
    JCheckBox cb = (JCheckBox)ie.getItem();
    if(cb isSelected())
        jlab.setText(cb.getText() + " is selected");
    else
        jlab.setText(cb.getText() + " is cleared");
}

public static void main(String[] args) {
    // Create the frame on the event dispatching thread.
    SwingUtilities.invokeLater(
        new Runnable() {
            public void run() {
                new JCheckBoxDemo();
            }
        });
}

Output from this example is shown here:
Radio Buttons

Radio buttons are a group of mutually exclusive buttons, in which only one button can be selected at any one time. They are supported by the `JRadioButton` class, which extends `JToggleButton`. `JRadioButton` provides several constructors. The one used in the example is shown here:

```java
JRadioButton(String str)
```

Here, `str` is the label for the button. Other constructors let you specify the initial selection state of the button and specify an icon.

In order for their mutually exclusive nature to be activated, radio buttons must be configured into a group. Only one of the buttons in the group can be selected at any time. For example, if a user presses a radio button that is in a group, any previously selected button in that group is automatically deselected. A button group is created by the `ButtonGroup` class. Its default constructor is invoked for this purpose. Elements are then added to the button group via the following method:

```java
void add(AbstractButton ab)
```

Here, `ab` is a reference to the button to be added to the group.

A `JRadioButton` generates action events, item events, and change events each time the button selection changes. Most often, it is the action event that is handled, which means that you will normally implement the `ActionListener` interface. Recall that the only method defined by `ActionListener` is `actionPerformed()`. Inside this method, you can use a number of different ways to determine which button was selected. First, you can check its action command by calling `getActionCommand()`. By default, the action command is the same as the button label, but you can set the action command to something else by calling `setActionCommand()` on the radio button. Second, you can call `getSource()` on the `ActionEvent` object and check that reference against the buttons. Third, you can check each radio button to find out which one is currently selected by calling `isSelected()` on each button. Finally, each button could use its own action event handler implemented as either an anonymous inner class or a lambda expression. Remember, each time an action event occurs, it means that the button being selected has changed and that one and only one button will be selected.

The following example illustrates how to use radio buttons. Three radio buttons are created. The buttons are then added to a button group. As explained, this is necessary to cause their mutually exclusive behavior. Pressing a radio button generates an action event, which is handled by `actionPerformed()`. Within that
handler, the `getActionCommand()` method gets the text that is associated with the radio button and uses it to set the text within a label.

```java
// Demonstrate JRadioButton
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

public class JRadioButtonDemo implements ActionListener {
    JLabel jlab;

    public JRadioButtonDemo() {

        // Set up the JFrame.
        JFrame jfrm = new JFrame("JRadioButtonDemo");
        jfrm.setLayout(new FlowLayout());
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        jfrm.setSize(250, 100);
    }
```
// Create radio buttons and add them to content pane.
JRadioButton b1 = new JRadioButton("A");
b1.addActionListener(this);
jfrm.add(b1);

JRadioButton b2 = new JRadioButton("B");
b2.addActionListener(this);
jfrm.add(b2);

JRadioButton b3 = new JRadioButton("C");
b3.addActionListener(this);
jfrm.add(b3);

// Define a button group.
ButtonGroup bg = new ButtonGroup();
bg.add(b1);
bg.add(b2);
bg.add(b3);

// Create a label and add it to the content pane.
jlab = new JLabel("Select One");
jfrm.add(jlab);

// Display the frame.
jfrm.setVisible(true);
}

// Handle button selection.
public void actionPerformed(ActionEvent ae) {
    jlab.setText("You selected " + ae.getActionCommand());
}

public static void main(String[] args) {
    // Create the frame on the event dispatching thread.

    SwingUtilities.invokeLater(
        new Runnable() {
            public void run() {
                new JRadioButtonDemo();
            }
        });
}
Output from the radio button example is shown here:

![JRadioButtonDemo](image)

**JTabbedPane**

**JTabbedPane** encapsulates a *tabbed pane*. It manages a set of components by linking them with tabs. Selecting a tab causes the component associated with that tab to come to the forefront. Tabbed panes are very common in the modern GUI, and you have no doubt used them many times. Given the complex nature of a tabbed pane, they are surprisingly easy to create and use.

**JTabbedPane** defines three constructors. We will use its default constructor, which creates an empty control with the tabs positioned across the top of the pane. The other two constructors let you specify the location of the tabs, which can be along any of the four sides. **JTabbedPane** uses the **SingleSelectionModel** model.

Tabs are added by calling **addTab()**. Here is one of its forms:

```java
void addTab(String name, Component comp)
```

Here, *name* is the name for the tab, and *comp* is the component that should be added to the tab. Often, the component added to a tab is a **JPanel** that contains a group of related components. This technique allows a tab to hold a set of components.

The general procedure to use a tabbed pane is outlined here:

1. Create an instance of **JTabbedPane**.
2. Add each tab by calling **addTab()**.
3. Add the tabbed pane to the content pane.

The following example illustrates a tabbed pane. The first tab is titled "Cities" and contains four buttons. Each button displays the name of a city. The second tab is titled "Colors" and contains three check boxes. Each check box displays the name of a color. The third tab is titled "Flavors" and contains one combo box. This enables the user to select one of three flavors.
// Demonstrate JTabbedPane.
import javax.swing.*;
import java.awt.*;

public class JTabbedPaneDemo {

    public JTabbedPaneDemo() {

        // Set up the JFrame.
        JFrame jfrm = new JFrame("JTabbedPaneDemo");
        jfrm.setLayout(new FlowLayout());
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        jfrm.setSize(400, 200);

        // Create the tabbed pane.
        JTabbedPane jtp = new JTabbedPane();
        jtp.addTab("Cities", new CitiesPanel());
        jtp.addTab("Colors", new ColorsPanel());
        jtp.addTab("Flavors", new FlavorsPanel());
        jfrm.add(jtp);
// Display the frame.
jfrm.setVisible(true);
}

public static void main(String[] args) {
    // Create the frame on the event dispatching thread.
    SwingUtilities.invokeLater(
        new Runnable() {
            public void run() {
                new JTabbedPaneDemo();
            }
        });
}

// Make the panels that will be added to the tabbed pane.
class CitiesPanel extends JPanel {

    public CitiesPanel() {
        JButton b1 = new JButton("New York");
        add(b1);
        JButton b2 = new JButton("London");
        add(b2);
        JButton b3 = new JButton("Hong Kong");
        add(b3);
        JButton b4 = new JButton("Tokyo");
        add(b4);
    }

    class ColorsPanel extends JPanel {

        public ColorsPanel() {
            JCheckBox cb1 = new JCheckBox("Red");
            add(cb1);
            JCheckBox cb2 = new JCheckBox("Green");
            add(cb2);
            JCheckBox cb3 = new JCheckBox("Blue");
            add(cb3);
        }
    }

    class FlavorsPanel extends JPanel {

        public FlavorsPanel() {
            JComboBox<String> jcb = new JComboBox<String>();
            jcb.addItem("Vanilla");
            jcb.addItem("Chocolate");
            jcb.addItem("Strawberry");
            add(jcb);
        }
    }
}
Output from the tabbed pane example is shown in the following three illustrations:

![JScrollPane example](image)

**JScrollPane**

**JScrollPane** is a lightweight container that automatically handles the scrolling of another component. The component being scrolled can be either an individual component, such as a table, or a group of components contained within another lightweight container, such as a **JPanel**. In either case, if the object being scrolled is larger than the viewable area, horizontal and/or vertical scroll bars are automatically provided, and the component can be scrolled through the pane. Because **JScrollPane** automates scrolling, it usually eliminates the need to manage individual scroll bars.

The viewable area of a scroll pane is called the *viewport*. It is a window in which the component being scrolled is displayed. Thus, the viewport displays the visible portion of the component being scrolled. The scroll bars scroll the component through the viewport. In its default behavior, a **JScrollPane** will dynamically add or remove a scroll bar as needed. For example, if the component is taller than the viewport, a vertical scroll bar is added. If the component will completely fit within the viewport, the scroll bars are removed.
**JScrollPane** defines several constructors. The one used in this chapter is shown here:

```java
JScrollPane(Component comp)
```

The component to be scrolled is specified by `comp`. Scroll bars are automatically displayed when the content of the pane exceeds the dimensions of the viewport. Here are the steps to follow to use a scroll pane:

1. Create the component to be scrolled.
2. Create an instance of **JScrollPane**, passing to it the object to scroll.
3. Add the scroll pane to the content pane.

The following example illustrates a scroll pane. First, a **JPanel** object is created, and 400 buttons are added to it, arranged into 20 columns. This panel is then added to a scroll pane, and the scroll pane is added to the content pane. Because the panel is larger than the viewport, vertical and horizontal scroll bars appear automatically. You can use the scroll bars to scroll the buttons into view.
/ Demonstrate JScrollPane.
import java.awt.*;
import javax.swing.*;

public class JScrollPaneDemo {

    public JScrollPaneDemo() {

        // Set up the JFrame. Use the default BorderLayout.
        JFrame jfrm = new JFrame("JScrollPaneDemo");
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        jfrm.setSize(400, 400);

        // Create a panel and add 400 buttons to it.
        JPanel jp = new JPanel();
        jp.setLayout(new GridLayout(20, 20));

        int b = 0;
        for(int i = 0; i < 20; i++) {
            for(int j = 0; j < 20; j++) {
                jp.add(new JButton("Button " + b));
                ++b;
            }
        }

        // Create the scroll pane.
        JScrollPane jsp = new JScrollPane(jp);

        // Add the scroll pane to the content pane.
        // Because the default border layout is used,
        // the scroll pane will be added to the center.
        jfrm.add(jsp, BorderLayout.CENTER);

        // Display the frame.
        jfrm.setVisible(true);
    }
}
Output from the scroll pane example is shown here:

```
public static void main(String[] args) {
    // Create the frame on the event dispatching thread.
    SwingUtilities.invokeLater(
        new Runnable() {
            public void run() {
                new JScrollPaneDemo();
            }
        };
    }
}
```

**JList**

In Swing, the basic list class is called **JList**. It supports the selection of one or more items from a list. Although the list often consists of strings, it is possible to create a list of just about any object that can be displayed. **JList** is so widely used in Java that it is highly unlikely that you have not seen one before.

In the past, the items in a **JList** were represented as **Object** references. However, beginning with JDK 7, **JList** was made generic and is now declared like this:
class JList<E>

Here, E represents the type of the items in the list.

JList provides several constructors. The one used here is

JList(E[] items)

This creates a JList that contains the items in the array specified by items.

JList is based on two models. The first is ListModel. This interface defines how access to the list data is achieved. The second model is the ListSelectionModel interface, which defines methods that determine what list item or items are selected.

Although a JList will work properly by itself, most of the time you will wrap a JList inside a JScrollPane. This way, long lists will automatically be scrollable, which simplifies GUI design. It also makes it easy to change the number of entries in a list without having to change the size of the JList component.

A JList generates a ListSelectionEvent when the user makes or changes a selection. This event is also generated when the user deselects an item. It is handled by implementing ListSelectionListener. This listener specifies only one method, called valueChanged(), which is shown here:

void valueChanged(ListSelectionEvent le)

Here, le is a reference to the event. Although ListSelectionEvent does provide some methods of its own, normally you will interrogate the JList object itself to determine what has occurred. Both ListSelectionEvent and ListSelectionListener are packaged in javax.swing.event.

By default, a JList allows the user to select multiple ranges of items within the list, but you can change this behavior by calling setSelectionMode(), which is defined by JList. It is shown here:

void setSelectionMode(int mode)

Here, mode specifies the selection mode. It must be one of these values defined by ListSelectionModel:

SINGLE_SELECTION
SINGLE_INTERVAL_SELECTION
MULTIPLE_INTERVAL_SELECTION

The default, multiple-interval selection, lets the user select multiple ranges of items
within a list. With single-interval selection, the user can select one range of items. With single selection, the user can select only a single item. Of course, a single item can be selected in the other two modes, too. It’s just that they also allow a range to be selected.

You can obtain the index of the first item selected, which will also be the index of the only selected item when using single-selection mode, by calling `getSelectedIndex()`, shown here:

```
    int getSelectedIndex()
```

Indexing begins at zero. So, if the first item is selected, this method will return 0. If no item is selected, –1 is returned.

Instead of obtaining the index of a selection, you can obtain the value associated with the selection by calling `getSelectedValue()`:

```
    E getSelectedValue()
```

It returns a reference to the first selected value. If no value has been selected, it returns `null`.

The following program demonstrates a simple `JList`, which holds a list of cities. Each time a city is selected in the list, a `ListSelectionEvent` is generated, which is handled by the `valueChanged()` method defined by `ListSelectionListener`. It responds by obtaining the index of the selected item and displaying the name of the selected city in a label.
// Demonstrate JList.
import javax.swing.*;
import javax.swing.event.*;
import java.awt.*;
import java.awt.event.*;

public class JListDemo {

    // Create an array of cities.
    String Cities[] = {"New York", "Chicago", "Houston",
                       "Denver", "Los Angeles", "Seattle",
                       "London", "Paris", "New Delhi",
                       "Hong Kong", "Tokyo", "Sydney"};

    public JListDemo() {

        // Set up the JFrame.
        JFrame jfrm = new JFrame("JListDemo");
        jfrm.setLayout(new FlowLayout());
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        jfrm.setSize(200, 200);

        // Create a JList.
        JList<String> jlst = new JList<String>(Cities);

        // Set the list selection mode to single-selection.
        jlst.setSelectionMode(ListSelectionModel.SINGLE_SELECTION);

        // Add the list to a scroll pane.
        JScrollPane jscrlp = new JScrollPane(jlst);

        // Set the preferred size of the scroll pane.
        jscrlp.setPreferredSize(new Dimension(120, 90));

        // Make a label that displays the selection.
        JLabel jlab = new JLabel("Choose a City");

        // Add selection listener for the list.
        jlst.addListSelectionListener(new ListSelectionListener() {
            public void valueChanged(ListSelectionEvent le) {
                // Get the index of the changed item.
                int idx = jlst.getSelectedIndex();

                // Display selection, if item was selected.
                if(idx != -1)
                    jlab.setText("Current selection: " + Cities[idx]);
            }
        });
    }
}
else // Otherwise, reprompt.
    jlab.setText("Choose a City");
}
});

// Add the list and label to the content pane.
jfrm.add(jscrlp);
jfrm.add(jlab);

// Display the frame.
jfrm.setVisible(true);

public static void main(String[] args) {
    // Create the frame on the event dispatching thread.

    SwingUtilities.invokeLater(
    new Runnable() {
        public void run() {
            new JListDemo();
        }
    });
}

Output from the list example is shown here:

![JListDemo window](image)

**JComboBox**

Swing provides a combo box (a combination of a text field and a drop-down list)
through the JComboBox class. A combo box normally displays one entry, but it will also display a drop-down list that allows a user to select a different entry. You can also create a combo box that lets the user enter a selection into the text field.

In the past, the items in a JComboBox were represented as Object references. However, beginning with JDK 7, JComboBox was made generic and is now declared like this:

class JComboBox<E>

Here, E represents the type of the items in the combo box.

The JComboBox constructor used by the example is shown here:

JComboBox(E[ ] items)

Here, items is an array that initializes the combo box. Other constructors are available.

 JComboBox uses the ComboBoxModel. Mutable combo boxes (those whose entries can be changed) use the MutableComboBoxModel.

In addition to passing an array of items to be displayed in the drop-down list, items can be dynamically added to the list of choices via the addItem( ) method, shown here:

 void addItem(E obj)

Here, obj is the object to be added to the combo box. This method must be used only with mutable combo boxes.

 JComboBox generates an action event when the user selects an item from the list. JComboBox also generates an item event when the state of selection changes, which occurs when an item is selected or deselected. Thus, changing a selection means that two item events will occur: one for the deselected item and another for the selected item. Often, it is sufficient to simply listen for action events, but both event types are available for your use.

One way to obtain the item selected in the list is to call getSelectedItem( ) on the combo box. It is shown here:

 Object getSelectedItem( )

You will need to cast the returned value into the type of object stored in the list.

The following example demonstrates the combo box. The combo box contains entries for "Hourglass", "Analog", "Digital", and "Stopwatch". When a timepiece is
selected, an icon-based label is updated to display it. You can see how little code is required to use this powerful component.

```java
// Demonstrate JComboBox.
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

public class JComboBoxDemo {
    String timepieces[] = { "Hourglass", "Analogue", "Digital", "Stopwatch" };

    public JComboBoxDemo() {

        // Set up the JFrame.
        JFrame jfrm = new JFrame("JComboBoxDemo");
        jfrm.setLayout(new FlowLayout());
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        jfrm.setSize(400, 250);

        // Instantiate a combo box and add it to the content pane.
        JComboBox<String> jcb = new JComboBox<String>(timepieces);
        jfrm.add(jcb);
    }
}
```
// Create a label and add it to the content pane.
JLabel jlab = new JLabel(new ImageIcon("hourglass.png"));
jfrm.add(jlab);

// Handle selections.
jcb.addActionListener(new ActionListener() {
   public void actionPerformed(ActionEvent ae) {
      String s = (String) jcb.getSelectedItem();
      jlab.setIcon(new ImageIcon(s + ".png"));
   }
});

// Display the frame.
jfrm.setVisible(true);

public static void main(String[] args) {
   // Create the frame on the event dispatching thread.

   SwingUtilities.invokeLater(
      new Runnable() {
         public void run() {
            new JComboBoxDemo();
         }
      });
}

Output from the combo box example is shown here:
Trees

A tree is a component that presents a hierarchical view of data. The user has the ability to expand or collapse individual subtrees in this display. Trees are implemented in Swing by the JTree class. A sampling of its constructors is shown here:

```java
JTree(Object obj [])
JTree(Vector<?> v)
JTree(TreeNode tn)
```

In the first form, the tree is constructed from the elements in the array `obj`. The second form constructs the tree from the elements of vector `v`. In the third form, the tree whose root node is specified by `tn` specifies the tree.

Although JTree is packaged in javax.swing, its support classes and interfaces are packaged in javax.swing.tree. This is because the number of classes and interfaces needed to support JTree is quite large.

JTree relies on two models: TreeModel and TreeSelectionModel. A JTree generates a variety of events, but three relate specifically to trees: TreeExpansionEvent, TreeSelectionEvent, and TreeModelEvent. TreeExpansionEvent events occur when a node is expanded or collapsed. A TreeSelectionEvent is generated when the user selects or deselects a node within the tree. A TreeModelEvent is fired when the data or structure of the tree changes. The listeners for these events are TreeExpansionListener, TreeSelectionListener, and TreeModelListener, respectively. The tree event classes and listener interfaces are packaged in javax.swing.event.

The event handled by the sample program shown in this section is TreeSelectionEvent. To listen for this event, implement TreeSelectionListener. It defines only one method, called valueChanged(), which receives the TreeSelectionEvent object. You can obtain the path to the selected object by calling getPath(), shown here, on the event object:

```java
TreePath getPath()
```

It returns a TreePath object that describes the path to the changed node. The TreePath class encapsulates information about a path to a particular node in a tree. It provides several constructors and methods. In this book, only the toString() method is used. It returns a string that describes the path.

The TreeNode interface declares methods that obtain information about a tree node. For example, it is possible to obtain a reference to the parent node or an
enumeration of the child nodes. The **MutableTreeNode** interface extends **TreeNode**. It declares methods that can insert and remove child nodes or change the parent node.

The **DefaultMutableTreeNode** class implements the **MutableTreeNode** interface. It represents a node in a tree. One of its constructors is shown here:

```
DefaultMutableTreeNode(Object obj)
```

Here, *obj* is the object to be enclosed in this tree node. The new tree node doesn’t have a parent or children.

To create a hierarchy of tree nodes, the **add()** method of **DefaultMutableTreeNode** can be used. Its signature is shown here:

```
void add(MutableTreeNode child)
```

Here, *child* is a mutable tree node that is to be added as a child to the current node.

**JTree** does not provide any scrolling capabilities of its own. Instead, a **JTree** is typically placed within a **JScrollPane**. This way, a large tree can be scrolled through a smaller viewport.

Here are the steps to follow to use a tree:

1. Create an instance of **JTree**.
2. Create a **JScrollPane** and specify the tree as the object to be scrolled.
3. Add the tree to the scroll pane.
4. Add the scroll pane to the content pane.

The following example illustrates how to create a tree and handle selections. The program creates a **DefaultMutableTreeNode** instance labeled "Options". This is the top node of the tree hierarchy. Additional tree nodes are then created, and the **add()** method is called to connect these nodes to the tree. A reference to the top node in the tree is provided as the argument to the **JTree** constructor. The tree is then provided as the argument to the **JScrollPane** constructor. This scroll pane is then added to the content pane. Next, a label is created and added to the content pane. The tree selection is displayed in this label. To receive selection events from the tree, a **TreeSelectionListener** is registered for the tree. Inside the **valueChanged()** method, the path to the current selection is obtained and displayed.
// Demonstrate JTree.
import java.awt.*;
import javax.swing.event.*;
import javax.swing.*;
import javax.swing.tree.*;

public class JTreeDemo {

    public JTreeDemo() {

        // Set up the JFrame. Use default BorderLayout.
        JFrame jfrm = new JFrame("JTreeDemo");
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        jfrm.setSize(200, 250);

        // Create top node of tree.
        DefaultMutableTreeNode top = new DefaultMutableTreeNode("Options");

        // Create subtree of "A".
        DefaultMutableTreeNode a = new DefaultMutableTreeNode("A");
        top.add(a);
        DefaultMutableTreeNode a1 = new DefaultMutableTreeNode("A1");
        a.add(a1);
        DefaultMutableTreeNode a2 = new DefaultMutableTreeNode("A2");
        a.add(a2);

        // Create subtree of "B".
        DefaultMutableTreeNode b = new DefaultMutableTreeNode("B");
        top.add(b);
        DefaultMutableTreeNode b1 = new DefaultMutableTreeNode("B1");
        b.add(b1);
        DefaultMutableTreeNode b2 = new DefaultMutableTreeNode("B2");
        b.add(b2);
        DefaultMutableTreeNode b3 = new DefaultMutableTreeNode("B3");
        b.add(b3);

        // Create the tree.
        JTree tree = new JTree(top);
// Add the tree to a scroll pane.
JScrollPane jsp = new JScrollPane(tree);

// Add the scroll pane to the content pane.
jfrm.add(jsp);

// Add the label to the content pane.
JLabel jlab = new JLabel();
jfrm.add(jlab, BorderLayout.SOUTH);

// Handle tree selection events.
tree.addTreeSelectionListener(new TreeSelectionListener() {
   public void valueChanged(TreeSelectionEvent tse) {
      jlab.setText("Selection is " + tse.getPath());
   }
});

// Display the frame.
jfrm.setVisible(true);
}

public static void main(String[] args) {
   // Create the frame on the event dispatching thread.
   SwingUtilities.invokeLater(
      new Runnable() {
         public void run() {
            new JTreeDemo();
         }
      }
   );
}

Output from the tree example is shown here:
The string presented in the text field describes the path from the top tree node to the selected node.

**JTable**

*JTable* is a component that displays rows and columns of data. You can drag the cursor on column boundaries to resize columns. You can also drag a column to a new position. Depending on its configuration, it is also possible to select a row, column, or cell within the table, and to change the data within a cell. *JTable* is a sophisticated component that offers many more options and features than can be discussed here. (It is perhaps Swing’s most complicated component.) However, in its default configuration, *JTable* still offers substantial functionality that is easy to use—especially if you simply want to use the table to present data in a tabular format. The brief overview presented here will give you a general understanding of this powerful component.

Like *JTree*, *JTable* has many classes and interfaces associated with it. These are packaged in *javax.swing.table*.

At its core, *JTable* is conceptually simple. It is a component that consists of one or more columns of information. At the top of each column is a heading. In addition to describing the data in a column, the heading also provides the mechanism by which the user can change the size of a column or change the location of a column within the table. *JTable* does not provide any scrolling capabilities of its own. Instead, you will normally wrap a *JTable* inside a *JScrollPane*.

*JTable* supplies several constructors. The one used here is

```
JTable(Object data[ ][ ], Object colHeads[ ])
```
Here, \textit{data} is a two-dimensional array of the information to be presented, and \textit{colHeads} is a one-dimensional array with the column headings.

\textit{JTable} relies on three models. The first is the table model, which is defined by the \textbf{TableModel} interface. This model defines those things related to displaying data in a two-dimensional format. The second is the table column model, which is represented by \textbf{TableColumnModel}. \textit{JTable} is defined in terms of columns, and it is \textbf{TableColumnModel} that specifies the characteristics of a column. These two models are packaged in \texttt{javax.swing.table}. The third model determines how items are selected, and it is specified by the \textbf{ListSelectionModel}, which was described when \texttt{JList} was discussed.

\textit{JTable} can generate several different events. The two most fundamental to a table’s operation are \textbf{ListSelectionEvent} and \textbf{TableModelEvent}. A \textbf{ListSelectionEvent} is generated when the user selects something in the table. By default, \texttt{JTable} allows you to select one or more complete rows, but you can change this behavior to allow one or more columns, or one or more individual cells to be selected. A \textbf{TableModelEvent} is fired when that table’s data changes in some way. Handling these events requires a bit more work than it does to handle the events generated by the previously described components and is beyond the scope of this book. However, if you simply want to use \textit{JTable} to display data (as the following example does), then you don’t need to handle any events.

Here are the steps required to set up a simple \textit{JTable} that can be used to display data:

1. Create an instance of \textit{JTable}.
2. Create a \texttt{JScrollPane} object, specifying the table as the object to scroll.
3. Add the table to the scroll pane.
4. Add the scroll pane to the content pane.

The following example illustrates how to create and use a simple table. A one-dimensional array of strings called \texttt{colHeads} is created for the column headings. A two-dimensional array of strings called \texttt{data} is created for the table cells. You can see that each element in the array is an array of three strings. These arrays are passed to the \textit{JTable} constructor. The table is added to a scroll pane, and then the scroll pane is added to the content pane. The table displays the data in the \texttt{data} array. The default table configuration also allows the contents of a cell to be edited. Changes affect the underlying array, which is \texttt{data} in this case.
// Demonstrate JTable.
import java.awt.*;
import javax.swing.*;

public class JTableDemo {

    // Initialize column headings.
    String[] colHeads = { "Name", "Extension", "ID#" };

    // Initialize data.
    Object[][] data = {
        { "Gail", "4567", "865" },
        { "Ken", "7566", "555" },
        { "Viviane", "5634", "587" },
        { "Melanie", "7345", "922" },
        { "Anne", "1237", "333" },
        { "John", "5656", "314" },
        { "Matt", "5672", "217" },
        { "Claire", "6741", "444" },
        { "Erwin", "9023", "519" },
        { "Ellen", "1134", "532" },
        { "Jennifer", "5689", "112" },
        { "Ed", "9030", "133" },
        { "Helen", "6751", "145" }
    };

    public JTableDemo() {

        // Set up the JFrame. Use default BorderLayout.
        JFrame jfrm = new JFrame("JTableDemo");
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        jfrm.setSize(300, 300);

        // Create the table.
        JTable table = new JTable(data, colHeads);

        // Add the table to a scroll pane.
        JScrollPane jsp = new JScrollPane(table);
// Add the scroll pane to the content pane.
jfrm.add(jsp);

// Display the frame.
jfrm.setVisible(true);
}

public static void main(String[] args) {
   // Create the frame on the event dispatching thread.

   SwingUtilities.invokeLater(
      new Runnable() {
         public void run() {
            new JTableDemo();
         }
      }
   );
}

Output from this example is shown here:
33  Introducing Swing Menus

This chapter introduces another fundamental aspect of the Swing GUI environment: the menu. Menus form an integral part of many applications because they present the program’s functionality to the user. Because of their importance, Swing provides extensive support for menus. They are an area in which Swing’s power is readily apparent.

The Swing menu system supports several key elements, including

- The menu bar, which is the main menu for an application.
- The standard menu, which can contain either items to be selected or other menus (submenus).
- The popup menu, which is usually activated by right-clicking the mouse.
- The toolbar, which provides rapid access to program functionality, often paralleling menu items.
- The action, which enables two or more different components to be managed by a single object. Actions are commonly used with menus and toolbars.

Swing menus also support accelerator keys, which enable menu items to be selected without having to activate the menu, and mnemonics, which allow a menu item to be selected by the keyboard once the menu options are displayed.

Menu Basics

The Swing menu system is supported by a group of related classes. The ones used in this chapter are shown in Table 33-1, and they represent the core of the menu system. Although they may seem a bit confusing at first, Swing menus are quite easy to use. Swing allows a high degree of customization, if desired; however, you will normally use the menu classes as-is because they support all of the most needed options. For example, you can easily add images and keyboard shortcuts to a menu.
Here is a brief overview of how the classes fit together. To create the top-level menu for an application, you first create a `JMenuBar` object. This class is, loosely speaking, a container for menus. To the `JMenuBar` instance, you will add instances of `JMenu`. Each `JMenu` object defines a menu. That is, each `JMenu` object contains one or more selectable items. The items displayed by a `JMenu` are objects of `JMenuItem`. Thus, a `JMenuItem` defines a selection that can be chosen by the user.

As an alternative or adjunct to menus that descend from the menu bar, you can also create stand-alone, popup menus. To create a popup menu, first create an object of type `JPopupMenu`. Then, add `JMenuItem`s to it. A popup menu is normally activated by clicking the right mouse button when the mouse is over a component for which a popup menu has been defined.

In addition to “standard” menu items, you can also include check boxes and radio buttons in a menu. A check box menu item is created by `JCheckBoxMenuItem`. A radio button menu item is created by `JRadioButtonMenuItem`. Both of these classes extend `JMenuItem`. They can be used in standard menus and popup menus.

`JToolBar` creates a stand-alone component that is related to the menu. It is often used to provide fast access to functionality contained within the menus of the application. For example, a toolbar might provide fast access to the formatting commands supported by a word processor.

`JSeparator` is a convenience class that creates a separator line in a menu.

One key point to understand about Swing menus is that each menu item extends `AbstractButton`. Recall that `AbstractButton` is also the superclass of all of Swing’s button components, such as `JButton`. Thus, all menu items are, essentially, buttons. Obviously, they won’t actually look like buttons when used in a menu, but they will, in many ways, act like buttons. For example, selecting a menu item generates an action event in the same way that pressing a button does.

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>JMenuBar</td>
<td>An object that holds the top-level menu for the application.</td>
</tr>
<tr>
<td>JMenu</td>
<td>A standard menu. A menu consists of one or more <code>JMenuItem</code>s.</td>
</tr>
<tr>
<td>JMenuItem</td>
<td>An object that populates menus.</td>
</tr>
<tr>
<td>JCheckBoxMenuItem</td>
<td>A check box menu item.</td>
</tr>
<tr>
<td>JRadioButtonMenuItem</td>
<td>A radio button menu item</td>
</tr>
<tr>
<td>JSeparator</td>
<td>The visual separator between menu items.</td>
</tr>
<tr>
<td>JPopupMenu</td>
<td>A menu that is typically activated by right-clicking the mouse.</td>
</tr>
</tbody>
</table>

Table 33-1  The Core Swing Menu Classes
Another key point is that JMenuItem is a superclass of JMenu. This allows the creation of submenus, which are, essentially, menus within menus. To create a submenu, you first create and populate a JMenu object and then add it to another JMenu object. You will see this process in action in the following section.

As mentioned in passing previously, when a menu item is selected, an action event is generated. The action command string associated with that action event will, by default, be the name of the selection. Thus, you can determine which item was selected by examining the action command. Of course, you can also use separate anonymous inner classes or lambda expressions to handle each menu item’s action events. In this case, the menu selection is already known, and there is no need to examine the action command string to determine which item was selected.

Menus can also generate other types of events. For example, each time that a menu is activated, selected, or canceled, a MenuEvent is generated that can be listened for via a MenuListener. Other menu-related events include MenuKeyEvent, MenuDragMouseEvent, and PopupMenuEvent. In many cases, however, you need only watch for action events, and in this chapter, we will use only action events.

**An Overview of JMenuBar, JMenu, and JMenuItem**

Before you can create a menu, you need to know something about the three core menu classes: JMenuBar, JMenu, and JMenuItem. These form the minimum set of classes needed to construct a main menu for an application. JMenu and JMenuItem are also used by popup menus. Thus, these classes form the foundation of the menu system.

**JMenuBar**

As mentioned, JMenuBar is essentially a container for menus. Like all components, it inherits JComponent (which inherits Container and Component). It has only one constructor, which is the default constructor. Therefore, initially the menu bar will be empty, and you will need to populate it with menus prior to use. Each application has one and only one menu bar.

JMenuBar defines several methods, but often you will only need to use one: add(). The add() method adds a JMenu to the menu bar. It is shown here:

```
JMenu add(JMenu menu)
```
Here, menu is a JMenu instance that is added to the menu bar. A reference to the menu is returned. Menus are positioned in the bar from left to right, in the order in which they are added. If you want to add a menu at a specific location, then use this version of add( ), which is inherited from Container:

Component add(Component menu, int idx)

Here, menu is added at the index specified by idx. Indexing begins at 0, with 0 being the left-most menu.

In some cases, you might want to remove a menu that is no longer needed. You can do this by calling remove( ), which is inherited from Container. It has these two forms:

    void remove(Component menu)
    void remove(int idx)

Here, menu is a reference to the menu to remove, and idx is the index of the menu to remove. Indexing begins at zero.

Another method that is sometimes useful is getMenuCount( ), shown here:

    int getMenuCount( )

It returns the number of elements contained within the menu bar.

JMenuBar defines some other methods that you might find helpful in specialized applications. For example, you can obtain an array of references to the menus in the bar by calling getSubElements( ). You can determine if a menu is selected by calling isSelected( ).

Once a menu bar has been created and populated, it is added to a JFrame by calling setJMenuBar( ) on the JFrame instance. (Menu bars are not added to the content pane.) The setJMenuBar( ) method is shown here:

    void setJMenuBar(JMenuBar mb)

Here, mb is a reference to the menu bar. The menu bar will be displayed in a position determined by the look and feel. Usually, this is at the top of the window.

JMenu

JMenu encapsulates a menu, which is populated with JMenuItem. As mentioned, it is derived from JMenuItem. This means that one JMenu can be a selection in
another JMenu. This enables one menu to be a submenu of another. JMenu defines a number of constructors. For example, here is the one used in the examples in this chapter:

JMenu(String name)

This constructor creates a menu that has the title specified by name. Of course, you don’t have to give a menu a name. To create an unnamed menu, you can use the default constructor:

JMenu()

Other constructors are also supported. In each case, the menu is empty until menu items are added to it.

JMenu defines many methods. Here is a brief description of some commonly used ones. To add an item to the menu, use the add( ) method, which has a number of forms, including the two shown here:

JMenuItem add(JMenuItem item)
Component add(Component item, int idx)

Here, item is the menu item to add. The first form adds the item to the end of the menu. The second form adds the item at the index specified by idx. As expected, indexing starts at zero. Both forms return a reference to the item added. As a point of interest, you can also use insert( ) to add menu items to a menu.

You can add a separator (an object of type JSeparator) to a menu by calling addSeparator( ), shown here:

void addSeparator( )

The separator is added onto the end of the menu. You can insert a separator into a menu by calling insertSeparator( ), shown next:

void insertSeparator(int idx)

Here, idx specifies the zero-based index at which the separator will be added.

You can remove an item from a menu by calling remove( ). Two of its forms are shown here:

void remove(JMenuItem menu)
void remove(int idx)
In this case, *menu* is a reference to the item to remove and *idx* is the index of the item to remove.

You can obtain the number of items in the menu by calling `getMenuComponentCount()`, shown here:

```java
int getMenuComponentCount()
```

You can get an array of the items in the menu by calling `getMenuComponents()`, shown next:

```java
Component[] getMenuComponents()
```

An array containing the components is returned.

**JMenuItem**

`JMenuItem` encapsulates an element in a menu. This element can be a selection linked to some program action, such as Save or Close, or it can cause a submenu to be displayed. As mentioned, `JMenuItem` is derived from `AbstractButton`, and every item in a menu can be thought of as a special kind of button. Therefore, when a menu item is selected, an action event is generated. (This is similar to the way a `JButton` fires an action event when it is pressed.) `JMenuItem` defines many constructors. The ones used in this chapter are shown here:

```java
JMenuItem(String name)
JMenuItem(Icon image)
JMenuItem(String name, Icon image)
JMenuItem(String name, int mnem)
JMenuItem(Action action)
```

The first constructor creates a menu item with the name specified by `name`. The second creates a menu item that displays the image specified by `image`. The third creates a menu item with the name specified by `name` and the image specified by `image`. The fourth creates a menu item with the name specified by `name` and uses the keyboard mnemonic specified by `mnem`. This mnemonic enables you to select an item from the menu by pressing the specified key. The last constructor creates a menu item using the information specified in `action`. A default constructor is also supported.

Because menu items inherit `AbstractButton`, you have access to the functionality provided by `AbstractButton`. One such method that is often useful with menus is
setEnabled(), which you can use to enable or disable a menu item. It is shown here:

```java
void setEnabled(boolean enable)
```

If `enable` is `true`, the menu item is enabled. If `enable` is `false`, the item is disabled and cannot be selected.

## Create a Main Menu

Traditionally, the most commonly used menu is the *main menu*. This is the menu defined by the menu bar, and it is the menu that defines all (or nearly all) of the functionality of an application. Fortunately, Swing makes creating and managing the main menu easy. This section shows you how to construct a basic main menu. Subsequent sections will show you how to add options to it.

Constructing the main menu requires several steps. First, create the `JMenuBar` object that will hold the menus. Next, construct each menu that will be in the menu bar. In general, a menu is constructed by first creating a `JMenu` object and then adding `JMenuItem`s to it. After the menus have been created, add them to the menu bar. The menu bar, itself, must then be added to the frame by calling `setJMenuBar()`. Finally, for each menu item, you must add an action listener that handles the action event fired when the menu item is selected.

A good way to understand the process of creating and managing menus is to work through an example. Here is a program that creates a simple menu bar that contains three menus. The first is a standard File menu that contains Open, Close, Save, and Exit selections. The second menu is called Options, and it contains two submenus called Colors and Priority. The third menu is called Help, and it has one item: About. When a menu item is selected, the name of the selection is displayed in a label in the content pane. Sample output is shown in Figure 33-1.
// Demonstrate a simple main menu.

import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

class MenuDemo implements ActionListener {

    JLabel jlab;

    MenuDemo() {
        // Create a new JFrame container.
        JFrame jfrm = new JFrame("Menu Demo");

        // Specify FlowLayout for the layout manager.
        jfrm.setLayout(new FlowLayout());

        // Give the frame an initial size.
        jfrm.setSize(220, 200);

        // Terminate the program when the user closes the application.
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

        // Create a label that will display the menu selection.
        jlab = new JLabel();

        // Create the menu bar.
        JMenuBar jmb = new JMenuBar();

        // Create the File menu.
        JMenu jmFile = new JMenu("File");
        JMenuItem jmiOpen = new JMenuItem("Open");
        JMenuItem jmiClose = new JMenuItem("Close");
        JMenuItem jmiSave = new JMenuItem("Save");
        JMenuItem jmiExit = new JMenuItem("Exit");
        jmFile.add(jmiOpen);
        jmFile.add(jmiClose);
        jmFile.add(jmiSave);
        jmFile.addSeparator();
        jmFile.add(jmiExit);
        jmb.add(jmFile);
    }
}
// Create the Options menu.
JMenu jmOptions = new JMenu("Options");

// Create the Colors submenu.
JMenu jmColors = new JMenu("Colors");
JMenuItem jmiRed = new JMenuItem("Red");
JMenuItem jmiGreen = new JMenuItem("Green");
JMenuItem jmiBlue = new JMenuItem("Blue");
jmColors.add(jmiRed);
jmColors.add(jmiGreen);
jmColors.add(jmiBlue);
jmOptions.add(jmColors);

// Create the Priority submenu.
JMenu jmPriority = new JMenu("Priority");
JMenuItem jmiHigh = new JMenuItem("High");
JMenuItem jmiLow = new JMenuItem("Low");
jmPriority.add(jmiHigh);
jmPriority.add(jmiLow);
jmOptions.add(jmPriority);

// Create the Reset menu item.
JMenuItem jmiReset = new JMenuItem("Reset");
jmOptions.addSeparator();
jmOptions.add(jmiReset);
// Finally, add the entire options menu to
// the menu bar
jmb.add(jmOptions);

// Create the Help menu.
JMenu jmHelp = new JMenu("Help");
JMenuItem jmiAbout = new JMenuItem("About");
jmHelp.add(jmiAbout);
jmb.add(jmHelp);

// Add action listeners for the menu items.
jmiOpen.addActionListener(this);
jmiClose.addActionListener(this);
jmiSave.addActionListener(this);
jmiExit.addActionListener(this);
jmiRed.addActionListener(this);
jmiGreen.addActionListener(this);
jmiBlue.addActionListener(this);
jmiHigh.addActionListener(this);
jmiLow.addActionListener(this);
jmiReset.addActionListener(this);
jmiAbout.addActionListener(this);

// Add the label to the content pane.
jfrm.add(jlab);

// Add the menu bar to the frame.
jfrm.setJMenuBar(jmb);

// Display the frame.
jfrm.setVisible(true);
// Handle menu item action events.
public void actionPerformed(ActionEvent ae) {
    // Get the action command from the menu selection.
    String comStr = ae.getActionCommand();

    // If user chooses Exit, then exit the program.
    if(comStr.equals("Exit")) System.exit(0);

    // Otherwise, display the selection.
    jlab.setText(comStr + " Selected");
}

public static void main(String args[]) {
    // Create the frame on the event dispatching thread.
    SwingUtilities.invokeLater(new Runnable() {
        public void run() {
            new MenuDemo();
        }
    });
}

![Sample output from the MenuDemo program](image)

**Figure 33-1**  Sample output from the **MenuDemo** program

Let’s examine, in detail, how the menus in this program are created, beginning with the **MenuDemo** constructor. It starts by creating a **JFrame** and setting its layout manager, size, and default close operation. (These operations are described in Chapter 31.) A **JLabel** is then constructed. It will be used to display a menu selection. Next, the menu bar is constructed and a reference to it is assigned to **jmb** by this statement:

// Create the menu bar.
JMenuBar jmb = new JMenuBar();
Then, the File menu **jmFile** and its menu entries are created by this sequence:

```java
// Create the File menu.
JMenu jmFile = new JMenu("File");
JMenuItem jmiOpen = new JMenuItem("Open");
JMenuItem jmiClose = new JMenuItem("Close");
JMenuItem jmiSave = new JMenuItem("Save");
JMenuItem jmiExit = new JMenuItem("Exit");

The names Open, Close, Save, and Exit will be shown as selections in the menu. Next, the menu entries are added to the file menu by this sequence:

jmFile.add(jmiOpen);
jmFile.add(jmiClose);
jmFile.add(jmiSave);
jmFile.addSeparator();
jmFile.add(jmiExit);

Finally, the File menu is added to the menu bar with this line:

jmBar.add(jmFile);
```

Once the preceding code sequence completes, the menu bar will contain one entry: File. The File menu will contain four selections in this order: Open, Close, Save, and Exit. However, notice that a separator has been added before Exit. This visually separates Exit from the preceding three selections.

The Options menu is constructed using the same basic process as the File menu. However, the Options menu consists of two submenus, Colors and Priority, and a Reset entry. The submenus are first constructed individually and then added to the Options menu. The Reset item is added last. Then, the Options menu is added to the menu bar. The Help menu is constructed using the same process.

Notice that **MenuDemo** implements the ActionListener interface and action events generated by a menu selection are handled by the actionPerformed() method defined by **MenuDemo**. Therefore, the program adds this as the action listener for the menu items. Notice that no listeners are added to the Colors or Priority items because they are not actually selections. They simply activate submenus.

Finally, the menu bar is added to the frame by the following line:

```java
jFrame.setJMenuBar(jmBar);
```

As mentioned, menu bars are not added to the content pane. They are added directly to the JFrame.
The `actionPerformed( )` method handles the action events generated by the menu. It obtains the action command string associated with the selection by calling `getActionCommand( )` on the event. It stores a reference to this string in `comStr`. Then, it tests the action command against "Exit", as shown here:

```java
if(comStr.equals("Exit")) System.exit(0);
```

If the action command is "Exit", then the program terminates by calling `System.exit( )`. This method causes the immediate termination of a program and passes its argument as a status code to the calling process, which is usually the operating system. By convention, a status code of zero means normal termination. Anything else indicates that the program terminated abnormally. For all other menu selections, the choice is displayed.

At this point, you might want to experiment a bit with the `MenuDemo` program. Try adding another menu or adding additional items to an existing menu. It is important that you understand the basic menu concepts before moving on because this program will evolve throughout the course of this chapter.

### Add Mnemonics and Accelerators to Menu Items

The menu created in the preceding example is functional, but it is possible to make it better. In real applications, a menu usually includes support for keyboard shortcuts because they give an experienced user the ability to select menu items rapidly. Keyboard shortcuts come in two forms: mnemonics and accelerators. As it applies to menus, a mnemonic defines a key that lets you select an item from an active menu by typing the key. Thus, a mnemonic allows you to use the keyboard to select an item from a menu that is already being displayed. An accelerator is a key that lets you select a menu item without having to first activate the menu.

A mnemonic can be specified for both `JMenuItem` and `JMenu` objects. There are two ways to set the mnemonic for `JMenuItem`. First, it can be specified when an object is constructed using this constructor:

```java
JMenuItem(String name, int mnem)
```

In this case, the name is passed in `name` and the mnemonic is passed in `mnem`. Second, you can set the mnemonic by calling `setMnemonic( )`. To specify a mnemonic for `JMenu`, you must call `setMnemonic( )`. This method is inherited by both classes from `AbstractButton` and is shown next:
void setMnemonic(int mnem)

Here, `mnem` specifies the mnemonic. It should be one of the constants defined in `java.awt.event.KeyEvent`, such as `KeyEvent.VK_F` or `KeyEvent.VK_Z`. (There is another version of `setMnemonic()` that takes a `char` argument, but it is considered obsolete.) Mnemonics are not case sensitive, so in the case of `VK_A`, typing either `a` or `A` will work.

By default, the first matching letter in the menu item will be underscored. In cases in which you want to underscore a letter other than the first match, specify the index of the letter as an argument to `setDisplayMnemonicIndex()`, which is inherited by both `JMenu` and `JMenuItem` from `AbstractButton`. It is shown here:

void setDisplayedMnemonicIndex(int idx)

The index of the letter to underscore is specified by `idx`.

An accelerator can be associated with a `JMenuItem` object. It is specified by calling `setAccelerator()`, shown next:

void setAccelerator(KeyStroke ks)

Here, `ks` is the key combination that is pressed to select the menu item. `KeyStroke` is a class that contains several factory methods that construct various types of keystroke accelerators. The following are three examples:

static KeyStroke getKeyStroke(char ch)
static KeyStroke getKeyStroke(Character ch, int modifier)
static KeyStroke getKeyStroke(int ch, int modifier)

Here, `ch` specifies the accelerator character. In the first version, the character is specified as a `char` value. In the second, it is specified as an object of type `Character`. In the third, it is a value of type `KeyEvent`, previously described. The value of `modifier` must be one or more of the following constants, defined in the `java.awt.event.InputEvent` class:

<table>
<thead>
<tr>
<th>InputEvent.ALT_DOWN_MASK</th>
<th>InputEvent.ALT_GRAPH_DOWN_MASK</th>
</tr>
</thead>
<tbody>
<tr>
<td>InputEvent.CTRL_DOWN_MASK</td>
<td>InputEvent.META_DOWN_MASK</td>
</tr>
<tr>
<td>InputEvent.SHIFT_DOWN_MASK</td>
<td></td>
</tr>
</tbody>
</table>

Therefore, if you pass `VK_A` for the key character and `InputEvent.CTRL_DOWN_MASK` for the modifier, the accelerator key
combination is ctrl-a.

The following sequence adds both mnemonics and accelerators to the File menu created by the MenuDemo program in the previous section. After making this change, you can select the File menu by typing alt-f. Then, you can use the mnemonics o, c, s, or e to select an option. Alternatively, you can directly select a File menu option by pressing ctrl-o, ctrl-c, ctrl-s, or ctrl-e. Figure 33-2 shows how this menu looks when activated.

```java
// Create the File menu with mnemonics and accelerators.
JMenu jmFile = new JMenu("File");
jmFile.setMnemonic(KeyEvent.VK_F);

JMenuItem jmiOpen = new JMenuItem("Open",
    KeyEvent.VK_O);
jmiOpen.setAccelerator(
    KeyStroke.getKeyStroke(KeyEvent.VK_O,
        InputEvent.CTRL_DOWN_MASK));

JMenuItem jmiClose = new JMenuItem("Close",
    KeyEvent.VK_C);
jmiClose.setAccelerator(
    KeyStroke.getKeyStroke(KeyEvent.VK_C,
        InputEvent.CTRL_DOWN_MASK));

JMenuItem jmiSave = new JMenuItem("Save",
    KeyEvent.VK_S);
jmiSave.setAccelerator(
    KeyStroke.getKeyStroke(KeyEvent.VK_S,
        InputEvent.CTRL_DOWN_MASK));

JMenuItem jmiExit = new JMenuItem("Exit",
    KeyEvent.VK_E);
jmiExit.setAccelerator(
    KeyStroke.getKeyStroke(KeyEvent.VK_E,
        InputEvent.CTRL_DOWN_MASK));
```
Add Images and Tooltips to Menu Items

You can add images to menu items or use images instead of text. The easiest way to add an image is to specify it when the menu item is being constructed using one of these constructors:

    JMenuItem(Icon image)
    JMenuItem(String name, Icon image)

The first creates a menu item that displays the image specified by `image`. The second creates a menu item with the name specified by `name` and the image specified by `image`. For example, here the About menu item is associated with an image when it is created:

    ImageIcon icon = new ImageIcon("AboutIcon.gif");
    JMenuItem jmiAbout = new JMenuItem("About", icon);

After this addition, the icon specified by `icon` will be displayed next to the text "About" when the Help menu is displayed. This is shown in Figure 33-3. You can also add an icon to a menu item after the item has been created by calling `setIcon()`, which is inherited from `AbstractButton`. You can specify the horizontal alignment of the image relative to the text by calling `setHorizontalTextPosition()`.
You can specify a disabled icon, which is shown when the menu item is disabled, by calling `setIconDisabledIcon()`.

A tooltip is a small message that describes an item. It is automatically displayed if the mouse remains over the item for a moment. You can add a tooltip to a menu item by calling `setToolTipText()` on the item, specifying the text you want displayed. It is shown here:

```java
void setToolTipText(String msg)
```

In this case, `msg` is the string that will be displayed when the tooltip is activated. For example, this creates a tooltip for the About item:

```java
jmiAbout.setToolTipText("Info about the MenuDemo program.");
```

As a point of interest, `setToolTipText()` is inherited by `JMenuItem` from `JComponent`. This means you can add a tooltip to other types of components, such as a push button. You might want to try this on your own.

**Use JRadioButtonMenuItem and JCheckBoxMenuItem**

Although the type of menu items used by the preceding examples are, as a general rule, the most commonly used, Swing defines two others: check boxes and radio buttons. These items can streamline a GUI by allowing a menu to provide functionality that would otherwise require additional, stand-alone components. Also, sometimes, including check boxes or radio buttons in a menu simply seems the most
natural place for a specific set of features. Whatever your reason, Swing makes it easy to use check boxes and radio buttons in menus, and both are examined here.

To add a check box to a menu, create a `JCheckBoxMenuItem`. It defines several constructors. This is the one used in this chapter:

```
JCheckBoxMenuItem(String name)
```

Here, `name` specifies the name of the item. The initial state of the check box is unchecked. If you want to specify the initial state, you can use this constructor:

```
JCheckBoxMenuItem(String name, boolean state)
```

In this case, if `state` is `true`, the box is initially checked. Otherwise, it is cleared. `JCheckBoxMenuItem` also provides constructors that let you specify an icon. Here is one example:

```
JCheckBoxMenuItem(String name, Icon icon)
```

In this case, `name` specifies the name of the item and the image associated with the item is passed in `icon`. The item is initially unchecked. Other constructors are also supported.

Check boxes in menus work like stand-alone check boxes. For example, they generate action events and item events when their state changes. Check boxes are especially useful in menus when you have options that can be selected and you want to display their selected/deselected status.

![Figure 33-4](image-url)  The effects of check box (a) and radio button (b) menu items

A radio button can be added to a menu by creating an object of type `JRadioButtonMenuItem`. `JRadioButtonMenuItem` inherits `JMenuItem`. It
provides a rich assortment of constructors. The ones used in this chapter are shown here:

```
JRadioButtonMenuItem(String name)
JRadioButtonMenuItem(String name, boolean state)
```

The first constructor creates an unselected radio button menu item that is associated with the name passed in `name`. The second lets you specify the initial state of the button. If `state` is `true`, the button is initially selected. Otherwise, it is deselected. Other constructors let you specify an icon. Here is one example:

```
JRadioButtonMenuItem(String name, Icon icon, boolean state)
```

This creates a radio button menu item that is associated with the name passed in `name` and the image passed in `icon`. If `state` is `true`, the button is initially selected. Otherwise, it is deselected. Several other constructors are supported.

A `JRadioButtonMenuItem` works like a stand-alone radio button, generating item and action events. Like stand-alone radio buttons, menu-based radio buttons must be put into a button group in order for them to exhibit mutually exclusive selection behavior.

Because both `JCheckBoxMenuItem` and `JRadioButtonMenuItem` inherit `JMenuItem`, each has all of the functionality provided by `JMenuItem`. Aside from having the extra capabilities of check boxes and radio buttons, they act like and are used like other menu items.

To try check box and radio button menu items, first remove the code that creates the Options menu in the `MenuDemo` example program. Then substitute the following code sequence, which uses check boxes for the Colors submenu and radio buttons for the Priority submenu. After making the substitution, the Options menu will look like those shown in Figure 33-4.

```java
// Create the Options menu.
JMenu jmOptions = new JMenu("Options");

// Create the Colors submenu.
JMenu jmColors = new JMenu("Colors");
```
// Use check boxes for colors. This allows 
// the user to select more than one color.
JCheckBoxMenuItem jmiRed = new JCheckBoxMenuItem("Red");
JCheckBoxMenuItem jmiGreen = new JCheckBoxMenuItem("Green");
JCheckBoxMenuItem jmiBlue = new JCheckBoxMenuItem("Blue");

jmColors.add(jmiRed);
jmColors.add(jmiGreen);
jmColors.add(jmiBlue);
jmOptions.add(jmColors);

// Create the Priority submenu.
JMenu jmPriority = new JMenu("Priority");

// Use radio buttons for the priority setting.
// This lets the menu show which priority is used
// but also ensures that one and only one priority
// can be selected at any one time. Notice that
// the High radio button is initially selected.
JRadioButtonMenuItem jmiHigh =
    new JRadioButtonMenuItem("High", true);
JRadioButtonMenuItem jmiLow =
    new JRadioButtonMenuItem("Low");

jmPriority.add(jmiHigh);
jmPriority.add(jmiLow);
jmOptions.add(jmPriority);

// Create button group for the radio button menu items.
ButtonGroup bg = new ButtonGroup();
bg.add(jmiHigh);
bg.add(jmiLow);

// Create the Reset menu item.
JMenuItem jmiReset = new JMenuItem("Reset");
jmOptions.addSeparator();
jmOptions.add(jmiReset);

// Finally, add the entire options menu to
// the menu bar
jmb.add(jmOptions);

Create a Popup Menu
A popular alternative or addition to the menu bar is the popup menu. Typically, a popup menu is activated by clicking the right mouse button when over a component. Popup menus are supported in Swing by the JPopupMenu class. JPopupMenu has two constructors. In this chapter, only the default constructor is used:

JPopupMenu( )

It creates a default popup menu. The other constructor lets you specify a title for the menu. Whether this title is displayed is subject to the look and feel.

In general, popup menus are constructed like regular menus. First, create a JPopupMenu object, and then add menu items to it. Menu item selections are also handled in the same way: by listening for action events. The main difference between a popup menu and regular menu is the activation process.

Activating a popup menu requires three steps:

1. You must register a listener for mouse events.
2. Inside the mouse event handler, you must watch for the popup trigger.
3. When a popup trigger is received, you must show the popup menu by calling show( ).

Let’s examine each of these steps closely.

A popup menu is normally activated by clicking the right mouse button when the mouse pointer is over a component for which a popup menu is defined. Thus, the popup trigger is usually caused by right-clicking the mouse on a popup menu–enabled component. To listen for the popup trigger, implement the MouseListener interface and then register the listener by calling the addMouseListener( ) method. As described in Chapter 24, MouseListener defines the methods shown here:

void mouseClicked(MouseEvent me)
void mouseEntered(MouseEvent me)
void mouseExited(MouseEvent me)
void mousePressed(MouseEvent me)
void mouseReleased(MouseEvent me)

Of these, two are very important relative to the popup menu: mousePressed( ) and mouseReleased( ). Depending on the installed look and feel, either of these two events can trigger a popup menu. For this reason, it is often easier to use a MouseAdapter to implement the MouseListener interface and simply override mousePressed( ) and mouseReleased( ).
The MouseEvent class defines several methods, but only four are commonly needed when activating a popup menu. They are shown here:

```java
int getX()
int getY()
boolean isPopupTrigger()
Component getComponent()
```

The current X,Y location of the mouse relative to the source of the event is found by calling `getX()` and `getY()`. These are used to specify the upper-left corner of the popup menu when it is displayed. The `isPopupTrigger()` method returns `true` if the mouse event represents a popup trigger and `false` otherwise. You will use this method to determine when to pop up the menu. To obtain a reference to the component that generated the mouse event, call `getComponent()`.

To actually display the popup menu, call the `show()` method defined by JPopupMenu, shown next:

```java
void show(Component invoker, int upperX, int upperY)
```

Here, `invoker` is the component relative to which the menu will be displayed. The values of `upperX` and `upperY` define the X,Y location of the upper-left corner of the menu, relative to `invoker`. A common way to obtain the invoker is to call `getComponent()` on the event object passed to the mouse event handler.

The preceding theory can be put into practice by adding a popup Edit menu to the MenuDemo program shown at the start of this chapter. This menu will have three items called Cut, Copy, and Paste. Begin by adding the following instance variable to MenuDemo:

```java
JPopupMenu jpu;
```

The `jpu` variable will hold a reference to the popup menu.

Next, add the following code sequence to the MenuDemo constructor:
This sequence begins by constructing an instance of `JPopupMenu` and storing it in `jpu`. Then, it creates the three menu items, Cut, Copy, and Paste, in the usual way, and adds them to `jpu`. This finishes the construction of the popup Edit menu. Popup menus are not added to the menu bar or any other object.

Next, a `MouseListener` is added by creating an anonymous inner class. This class is based on the `MouseAdapter` class, which means that the listener need only override those methods that are relevant to the popup menu: `mousePressed()` and `mouseReleased()`. The adapter provides default implementations of the other `MouseListener` methods. Notice that the mouse listener is added to `jfrm`. This means that a right-button click inside any part of the content pane will trigger the popup menu.

The `mousePressed()` and `mouseReleased()` methods call `isPopupTrigger()` to determine if the mouse event is a popup trigger event. If it is, the popup menu is displayed by calling `show()`. The invoker is obtained by calling `getComponent()` on the mouse event. In this case, the invoker will be the content pane. The X,Y coordinates of the upper-left corner are obtained by calling `getX()` and `getY()`. This makes the menu pop up with its upper-left corner directly under the mouse pointer.
Finally, you also need to add these action listeners to the program. They handle the action events fired when the user selects an item from the popup menu.

```java
jmiCut.addActionListener(this);
jmiCopy.addActionListener(this);
jmiPaste.addActionListener(this);
```

After you have made these additions, the popup menu can be activated by clicking the right mouse button anywhere inside the content pane of the application. Figure 33-5 shows the result.

One other point about the preceding example. Because the invoker of the popup menu is always `jfrm`, in this case, you could pass it explicitly rather than calling `getComponent()`. To do so, you must make `jfrm` into an instance variable of the `MenuDemo` class (rather than a local variable) so that it is accessible to the inner class. Then you can use this call to `show()` to display the popup menu:

```java
jpu.show(jfrm, me.getX(), me.getY());
```

Although this works in this example, the advantage of using `getComponent()` is that the popup menu will automatically pop up relative to the invoking component. Thus, the same code could be used to display any popup menu relative to its invoking object.

![Figure 33-5 A popup Edit menu](image)

### Create a Toolbar

A toolbar is a component that can serve as both an alternative and as an adjunct to a menu. A toolbar contains a list of buttons (or other components) that give the user immediate access to various program options. For example, a toolbar might contain buttons that select various font options, such as bold, italics, highlight, or underline.
These options can be selected without needing to drop through a menu. Typically, toolbar buttons show icons rather than text, although either or both are allowed. Furthermore, tooltips are often associated with icon-based toolbar buttons. Toolbars can be positioned on any side of a window by dragging the toolbar, or they can be dragged out of the window entirely, in which case they become free floating.

In Swing, toolbars are instances of the `JToolBar` class. Its constructors enable you to create a toolbar with or without a title. You can also specify the layout of the toolbar, which will be either horizontal or vertical. The `JToolBar` constructors are shown here:

```java
JToolBar( )
JToolBar(String title)
JToolBar(int how)
JToolBar(String title, int how)
```

The first constructor creates a horizontal toolbar with no title. The second creates a horizontal toolbar with the title specified by `title`. The title will show only when the toolbar is dragged out of its window. The third creates a toolbar that is oriented as specified by `how`. The value of `how` must be either `JToolBar.VERTICAL` or `JToolBar.HORIZONTAL`. The fourth constructor creates a toolbar that has the title specified by `title` and is oriented as specified by `how`.

A toolbar is typically used with a window that uses a border layout. There are two reasons for this. First, it allows the toolbar to be initially positioned along one of the four border positions. Frequently, the top position is used. Second, it allows the toolbar to be dragged to any side of the window.

In addition to dragging the toolbar to different locations within a window, you can also drag it out of the window. Doing so creates an undocked toolbar. If you specify a title when you create the toolbar, then that title will be shown when the toolbar is undocked.

You add buttons (or other components) to a toolbar in much the same way that you add them to a menu bar. Simply call `add()` The components are shown in the toolbar in the order in which they are added.

Once you have created a toolbar, you do not add it to the menu bar (if one exists). Instead, you add it to the window container. As mentioned, typically you will add a toolbar to the top (that is, north) position of a border layout, using a horizontal orientation. The component that will be affected is added to the center of the border layout. Using this approach causes the program to begin running with the toolbar in the expected location. However, you can drag the toolbar to any of the other positions. Of course, you can also drag the toolbar out of the window.
To illustrate the toolbar, we will add one to the **MenuDemo** program. The toolbar will present three debugging options: set a breakpoint, clear a breakpoint, and resume program execution. Three steps are needed to add the toolbar.

First, remove this line from the program:

```java
def setLayout(new FlowLayout());
```

By removing this line, the **JFrame** automatically uses a border layout.

Second, because **BorderLayout** is being used, change the line that adds the label **jlab** to the frame, as shown next:

```java
jfrm.add(jlab, BorderLayout.CENTER);
```

This line explicitly adds **jlab** to the center of the border layout. (Explicitly specifying the center position is technically not necessary because, by default, components are added to the center when a border layout is used. However, explicitly specifying the center makes it clear to anyone reading the code that a border layout is being used and that **jlab** goes in the center.)

Next, add the following code, which creates the Debug toolbar:
Let's look at this code closely. First, a `JToolBar` is created and given the title "Debug". Then, a set of `ImageIcon` objects are created that hold the images for the toolbar buttons. Next, three toolbar buttons are created. Notice that each has an image, but no text. Also, each is explicitly given an action command and a tooltip. The action commands are set because the buttons are not given names when they are constructed. Tooltips are especially useful when applied to icon-based toolbar components because sometimes it’s hard to design images that are intuitive to all users. The buttons are then added to the toolbar, and the toolbar is added to the north side of the border layout of the frame.

Finally, add the action listeners for the toolbar, as shown here:
// Add the toolbar action listeners.
btnSet.addActionListener(this);
btnClear.addActionListener(this);
btnResume.addActionListener(this);

Each time the user presses a toolbar button, an action event is fired, and it is handled in the same way as the other menu-related events. Figure 33-6 shows the toolbar in action.

Use Actions

Often, a toolbar and a menu item contain items in common. For example, the same functions provided by the Debug toolbar in the preceding example might also be offered through a menu selection. In such a case, selecting an option (such as setting a breakpoint) causes the same action to occur, independently of whether the menu or the toolbar was used. Also, both the toolbar button and the menu item would (most likely) use the same icon. Furthermore, when a toolbar button is disabled, the corresponding menu item would also need to be disabled. Such a situation would normally lead to a fair amount of duplicated, interdependent code, which is less than optimal. Fortunately, Swing provides a solution: the action.

An action is an instance of the Action interface. Action extends the ActionListener interface and provides a means of combining state information with the actionPerformed( ) event handler. This combination allows one action to manage two or more components. For example, an action lets you centralize the control and handling of a toolbar button and a menu item. Instead of having to duplicate code, your program need only create an action that automatically handles both components.

Because Action extends ActionListener, an action must provide an implementation of the actionPerformed( ) method. This handler will process the action events generated by the objects linked to the action.
In addition to the inherited `actionPerformed()` method, `Action` defines several methods of its own. One of particular interest is `putValue()`. It sets the value of the various properties associated with an action and is shown here:

```java
void putValue(String key, Object val)
```

It assigns `val` to the property specified by `key` that represents the desired property. Although not used by the example that follows, it is helpful to note that `Action` also supplies the `getValue()` method that obtains a specified property. It is shown here:

```java
Object getValue(String key)
```

It returns a reference to the property specified by `key`.

The key values used by `putValue()` and `getValue()` include those shown here:
For example, to set the mnemonic to the letter X, use this call to `putValue()`:

```java
actionOb.putValue(MNEMONIC_KEY, KeyEvent.VK_X);
```

One Action property that is not accessible through `putValue()` and `getValue()` is the enabled/disabled status. For this, you use the `setEnabled()` and `isEnabled()` methods. They are shown here:

```java
void setEnabled(boolean enabled)
boolean isEnabled()
```
For `setEnabled( )`, if `enabled` is `true`, the action is enabled. Otherwise, it is disabled. If the action is enabled, `isEnabled( )` returns `true`. Otherwise, it returns `false`.

Although you can implement all of the `Action` interface yourself, you won’t usually need to. Instead, Swing provides a partial implementation called `AbstractAction` that you can extend. By extending `AbstractAction`, you need implement only one method: `actionPerformed( )`. The other `Action` methods are provided for you. `AbstractAction` provides three constructors. The one used in this chapter is shown here:

```
AbstractAction(String name, Icon image)
```

It constructs an `AbstractAction` that has the name specified by `name` and the icon specified by `image`.

Once you have created an action, it can be added to a `JToolBar` and used to construct a `JMenuItem`. To add an action to a `JToolBar`, use this version of `add( )`:

```
JButton add(Action actObj)
```

Here, `actObj` is the action that is being added to the toolbar. The properties defined by `actObj` are used to create a toolbar button. To create a menu item from an action, use this `JMenuItem` constructor:

```
JMenuItem(Action actObj)
```

Here, `actObj` is the action used to construct a menu item according to its properties.

NOTE In addition to `JToolBar` and `JMenuItem`, actions are also supported by several other Swing components, such as `JPopupMenu`, `JButton`, `JRadioButton`, and `JCheckBox`. `JRadioButtonMenuItem` and `JCheckBoxMenuItem` also support actions.

To illustrate the benefit of actions, we will use them to manage the Debug toolbar created in the previous section. We will also add a Debug submenu under the Options main menu. The Debug submenu will contain the same selections as the Debug toolbar: Set Breakpoint, Clear Breakpoint, and Resume. The same actions that support these items in the toolbar will also support these items in the menu. Therefore, instead of having to create duplicate code to handle both the toolbar and menu, both are handled by the actions.

Begin by creating an inner class called `DebugAction` that extends `AbstractAction`, as shown here:
DebugAction extends AbstractAction. It creates an action class that will be used to define the properties associated with the Debug menu and toolbar. Its constructor has five parameters that let you specify the following items:

- Name
- Icon
- Mnemonic
- Accelerator
- Tooltip

The first two are passed to AbstractAction’s constructor via super. The other three
properties are set through calls to `putValue()`.

The `actionPerformed()` method of `DebugAction` handles events for the action. This means that when an instance of `DebugAction` is used to create a toolbar button and a menu item, events generated by either of those components are handled by the `actionPerformed()` method in `DebugAction`. Notice that this handler displays the selection in `jlab`. In addition, if the Set Breakpoint option is selected, then the Clear Breakpoint option is enabled and the Set Breakpoint option is disabled. If the Clear Breakpoint option is selected, then the Set Breakpoint option is enabled and the Clear Breakpoint option is disabled. This illustrates how an action can be used to enable or disable a component. When an action is disabled, it is disabled for all uses of that action. In this case, if Set Breakpoint is disabled, then it is disabled both in the toolbar and in the menu.

Next, add these `DebugAction` instance variables to `MenuDemo`:

```java
DebugAction setAct;
DebugAction clearAct;
DebugAction resumeAct;
```

Next, create three `ImageIcon` instances that represent the Debug options, as shown here:

```java
// Load the images for the actions.
ImageIcon setIcon = new ImageIcon("setBP.gif");
ImageIcon clearIcon = new ImageIcon("clearBP.gif");
ImageIcon resumeIcon = new ImageIcon("resume.gif");
```

Now, create the actions that manage the Debug options, as shown here:
// Create actions.
setAct =
    new DebugAction("Set Breakpoint",
    setIcon,
    KeyEvent.VK_S,
    KeyEvent.VK_B,
    "Set a break point.");

clearAct =
    new DebugAction("Clear Breakpoint",
    clearIcon,
    KeyEvent.VK_C,
    KeyEvent.VK_L,
    "Clear a break point.");

resumeAct =
    new DebugAction("Resume",
    resumeIcon,
    KeyEvent.VK_R,
    KeyEvent.VK_R,
    "Resume execution after breakpoint.");

// Initially disable the Clear Breakpoint option.
clearAct.setEnabled(false);

Notice that the accelerator for Set Breakpoint is B and the accelerator for Clear Breakpoint is L. The reason these keys are used rather than S and C is that these keys are already allocated by the File menu for Save and Close. However, they can still be used as mnemonics because each mnemonic is localized to its own menu. Also notice that the action that represents Clear Breakpoint is initially disabled. It will be enabled only after a breakpoint has been set.

Next, use the actions to create buttons for the toolbar and then add those buttons to the toolbar, as shown here:
Finally, create the Debug menu, as shown next:

```java
// Create a Debug toolbar.
JToolBar jtb = new JToolBar("Breakpoints");

// Add the buttons to the toolbar.
jtb.add(jbtnSet);
jtb.add(jbtnClear);
jtb.add(jbtnResume);

// Add the toolbar to the north position of
// the content pane.
jfrm.add(jtb, BorderLayout.NORTH);
```

After making these changes and additions, the actions that you created will be used to manage both the Debug menu and the toolbar. Thus, changing a property in the action (such as disabling it) will affect all uses of that action. The program will now look as shown in Figure 33-7.
Put the Entire MenuDemo Program Together

Throughout the course of this discussion, many changes and additions have been made to the MenuDemo program shown at the start of the chapter. Before concluding, it will be helpful to assemble all the pieces. Doing so not only eliminates any ambiguity about the way the pieces fit together, but it also gives you a complete menu demonstration program that you can experiment with.

The following version of MenuDemo includes all of the additions and enhancements described in this chapter. For clarity, the program has been reorganized, with separate methods being used to construct the various menus and toolbar. Notice that several of the menu-related variables, such as jmb, jmFile, and jtb, have been made into instance variables.
// The complete MenuDemo program.

import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

class MenuDemo implements ActionListener {

    JLabel jlab;
    JMenuBar jmb;
    JToolBar jtb;
    JPopupMenu jpu;

    DebugAction setAct;
    DebugAction clearAct;
    DebugAction resumeAct;

    MenuDemo() {
        // Create a new JFrame container.
        JFrame jfrm = new JFrame("Complete Menu Demo");

        // Use default border layout.

        // Give the frame an initial size.
        jfrm.setSize(360, 200);

        // Terminate the program when the user closes the application.
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

        // Create a label that will display the menu selection.
        jlab = new JLabel();

        // Create the menu bar.
        jmb = new JMenuBar();

        // Make the File menu.
        makeFileMenu();
    }
}
// Construct the Debug actions.
makeActions();

// Make the toolbar.
makeToolBar();

// Make the Options menu.
makeOptionsMenu();

// Make the Help menu.
makeHelpMenu();

// Make the Edit popup menu.
makeEditPUMenu();

// Add a listener for the popup trigger.
jfrm.addMouseListener(new MouseAdapter() {
    public void mousePressed(MouseEvent me) {
        if(me.isPopupTrigger())
            jpu.show(me.getComponent(), me.getX(), me.getY());
    }
    public void mouseReleased(MouseEvent me) {
        if(me.isPopupTrigger())
            jpu.show(me.getComponent(), me.getX(), me.getY());
    }
});
// Add the label to the center of the content pane.
jfrm.add(jlab, SwingConstants.CENTER);

// Add the toolbar to the north position of
// the content pane.
jfrm.add(jtb, BorderLayout.NORTH);

// Add the menu bar to the frame.
jfrm.setJMenuBar(jmb);

// Display the frame.
jfrm.setVisible(true);
}

// Handle menu item action events.
// This does NOT handle events generated
// by the Debug options.
public void actionPerformed(ActionEvent ae) {
    // Get the action command from the menu selection.
    String comStr = ae.getActionCommand();

    // If user chooses Exit, then exit the program.
    if(comStr.equals("Exit")) System.exit(0);

    // Otherwise, display the selection.
    jlab.setText(comStr + " Selected");
}
// An action class for the Debug menu
// and toolbar.
class DebugAction extends AbstractAction {
   public DebugAction(String name, Icon image, int mnem,
                        int accel, String tTip) {
      super(name, image);
      putValue(ACCELERATOR_KEY,
               KeyStroke.getKeyStroke(accel,
                                  InputEvent.CTRL_DOWN_MASK));
      putValue(MNEMONIC_KEY, mnem);
      putValue(SHORT_DESCRIPTION, tTip);
   }

   // Handle events for both the toolbar and the
   // Debug menu.
   public void actionPerformed(ActionEvent ae) {
      String comStr = ae.getActionCommand();

      jlab.setText(comStr + " Selected");

      // Toggle the enabled status of the
      // Set and Clear Breakpoint options.
      if(comStr.equals("Set Breakpoint")) {
         clearAct.setEnabled(true);
         setAct.setEnabled(false);
      } else if(comStr.equals("Clear Breakpoint")) {
         clearAct.setEnabled(false);
         setAct.setEnabled(true);
      }
   }
}
// Create the File menu with mnemonics and accelerators.
void makeFileMenu() {
    JMenu jmFile = new JMenu("File");
    jmFile.setMnemonic(KeyEvent.VK_F);

    JMenuItem jmiOpen = new JMenuItem("Open",
        KeyEvent.VK_O);
    jmiOpen.setAccelerator(
        KeyStroke.getKeyStroke(KeyEvent.VK_O,
            InputEvent.CTRL_DOWN_MASK));

    JMenuItem jmiClose = new JMenuItem("Close",
        KeyEvent.VK_C);
    jmiClose.setAccelerator(
        KeyStroke.getKeyStroke(KeyEvent.VK_C,
            InputEvent.CTRL_DOWN_MASK));

    JMenuItem jmiSave = new JMenuItem("Save",
        KeyEvent.VK_S);
    jmiSave.setAccelerator(
        KeyStroke.getKeyStroke(KeyEvent.VK_S,
            InputEvent.CTRL_DOWN_MASK));
JMenuItem jmiExit = new JMenuItem("Exit",
        KeyEvent.VK_E);

jmiExit.setAccelerator(
        KeyStroke.getKeyStroke(KeyEvent.VK_E,
        InputEvent.CTRL_DOWN_MASK));

jmFile.add(jmiOpen);
jmFile.add(jmiClose);
jmFile.add(jmiSave);
jmFile.addSeparator();
jmFile.add(jmiExit);
jmb.add(jmFile);

    // Add the action listeners for the File menu.
    jmiOpen.addActionListener(this);
    jmiClose.addActionListener(this);
    jmiSave.addActionListener(this);
    jmiExit.addActionListener(this);
}

    // Create the Options menu.
    void makeOptionsMenu() {
        JMenuItem jmOptions = new JMenuItem("Options");

             // Create the Colors submenu.
             JMenuItem jmColors = new JMenuItem("Colors");

             // Use check boxes for colors. This allows
             // the user to select more than one color.
             JCheckBoxMenuItem jmiRed = new JCheckBoxMenuItem("Red");
             JCheckBoxMenuItem jmiGreen = new JCheckBoxMenuItem("Green");
             JCheckBoxMenuItem jmiBlue = new JCheckBoxMenuItem("Blue");
// Add the items to the Colors menu.
jmColors.add(jmiRed);
jmColors.add(jmiGreen);
jmColors.add(jmiBlue);
jmOptions.add(jmColors);

// Create the Priority submenu.
JMenu jmPriority = new JMenu("Priority");

// Use radio buttons for the priority setting.
// This lets the menu show which priority is used
// but also ensures that one and only one priority
// can be selected at any one time. Notice that
// the High radio button is initially selected.
JRadioButtonMenuItem jmiHigh =
    new JRadioButtonMenuItem("High", true);
JRadioButtonMenuItem jmiLow =
    new JRadioButtonMenuItem("Low");

// Add the items to the Priority menu.
jmPriority.add(jmiHigh);
jmPriority.add(jmiLow);
jmOptions.add(jmPriority);

// Create a button group for the radio button
// menu items.
ButtonGroup bg = new ButtonGroup();
bg.add(jmiHigh);
bg.add(jmiLow);

// Now, create a Debug submenu that goes under
// the Options menu bar item. Use actions to
// create the items.
JMenu jmDebug = new JMenu("Debug");
JMenuItem jmiSetBP = new JMenuItem(setAct);
JMenuItem jmiClearBP = new JMenuItem(clearAct);
JMenuItem jmiResume = new JMenuItem(resumeAct);

// Add the items to the Debug menu.
jmDebug.add(jmiSetBP);
jmDebug.add(jmiClearBP);
jmDebug.add(jmiResume);
jmOptions.add(jmDebug);

// Create the Reset menu item.
JMenuItem jmiReset = new JMenuItem("Reset");
jmOptions.addSeparator();
jmOptions.add(jmiReset);

// Finally, add the entire options menu to
// the menu bar
jmb.add(jmOptions);
// Add the action listeners for the Options menu,
// except for those supported by the Debug menu.
jmiRed.addActionListener(this);
jmiGreen.addActionListener(this);
jmiBlue.addActionListener(this);
jmiHigh.addActionListener(this);
jmiLow.addActionListener(this);
jmiReset.addActionListener(this);
}

// Create the Help menu.
void makeHelpMenu() {
    JMenu jmHelp = new JMenu("Help");

    // Add an icon to the About menu item.
    ImageIcon icon = new ImageIcon("AboutIcon.gif");

    JMenuItem jmiAbout = new JMenuItem("About", icon);
    jmiAbout.setToolTipText("Info about the MenuDemo program.");
    jmHelp.add(jmiAbout);
    jmb.add(jmHelp);
}
// Add action listener for About.
jmiAbout.addActionListener(this);
}

// Construct the actions needed by the Debug menu
// and toolbar.
void makeActions() {
    // Load the images for the actions.
    ImageIcon setIcon = new ImageIcon("setBP.gif");
    ImageIcon clearIcon = new ImageIcon("clearBP.gif");
    ImageIcon resumeIcon = new ImageIcon("resume.gif");

    // Create actions.
    setAct =
        new DebugAction("Set Breakpoint",
                        setIcon,
                        KeyEvent.VK_S,
                        KeyEvent.VK_B,
                        "Set a break point.");

    clearAct =
        new DebugAction("Clear Breakpoint",
                        clearIcon,
                        KeyEvent.VK_C,
                        KeyEvent.VK_L,
                        "Clear a break point.");
resumeAct =
    new DebugAction("Resume",
        resumeIcon,
        KeyEvent.VK_R,
        KeyEvent.VK_R,
        "Resume execution after breakpoint.");

    // Initially disable the Clear Breakpoint option.
    clearAct.setEnabled(false);
}

// Create the Debug toolbar.
void makeToolBar() {
    // Create the toolbar buttons by using the actions.
    JButton jbtnSet = new JButton(setAct);
    JButton jbtnClear = new JButton(clearAct);
    JButton jbtnResume = new JButton(resumeAct);

    // Create the Debug toolbar.
    jtb = new JToolBar("Breakpoints");

    // Add the buttons to the toolbar.
    jtb.add(jbtnSet);
    jtb.add(jbtnClear);
    jtb.add(jbtnResume);
}
Continuing Your Exploration of Swing

Swing defines a very large GUI toolkit. It has many more features that you will want to explore on your own. For example, it supplies dialog classes, such as `JOptionPane` and `JDialog`, that you can use to streamline the construction of dialog windows. It also provides additional controls beyond those introduced in Chapter 31. Two you will want to explore are `JSpinner` (which creates a spin control) and `JFormattedTextField` (which supports formatted text). You will also want to experiment with defining your own models for the various components. Frankly, the best way to become familiar with Swing’s capabilities is to experiment with it.
PART
INTRODUCING GUI PROGRAMMING WITH JAVAFX

CHAPTER 34
Introducing JavaFX GUI Programming

CHAPTER 35
Exploring JavaFX Controls

CHAPTER 36
Introducing JavaFX Menus
CHAPTER
Like all successful languages, Java continues to evolve and improve. This also applies to its libraries. One of the most important examples of this evolutionary process is found in its GUI frameworks. As explained earlier in the book, the original GUI framework was the AWT. Because of its several limitations, it was soon followed by Swing, which offered a far superior approach to creating GUIs. Swing was so successful that it has remained the primary Java GUI framework for nearly two decades. However, Swing was designed when the enterprise application dominated software development. Today, consumer applications, and especially mobile apps, have risen in importance, and such applications often demand a GUI that has “visual sparkle.” Furthermore, no matter the type of application, the trend is toward more exciting visual effects. To better handle these types of GUIs, a new approach was needed, and this lead to the creation of JavaFX. JavaFX is Java’s next-generation client platform and GUI framework.

JavaFX provides a powerful, streamlined, flexible framework that simplifies the creation of modern, visually exciting GUIs. As such, it is a very large system, and, as was the case with Swing discussed in Part III, it is not possible to describe it fully in this book. Instead, the purpose of this and the next two chapters is to introduce several of its key features and techniques. Once you understand the fundamentals, you will find it easy to explore other aspects of JavaFX on your own.

One question that naturally arises relating to JavaFX is this: Is JavaFX designed as a replacement for Swing? The answer is a qualified Yes. However, given the large amount of Swing legacy code and the legions of programmers who know how to program for Swing, Swing will be in use for a very long time. This is especially true for enterprise applications. Nevertheless, JavaFX has clearly been positioned as the platform of the future. It is expected that, over the next few years, JavaFX will supplant Swing for new projects. JavaFX is something that no Java programmer can afford to ignore.

Before continuing, it is important to mention that the development of JavaFX occurred in two main phases. The original JavaFX was based on a scripting language called JavaFX Script. However, JavaFX Script has been discontinued. Beginning with the release of JavaFX 2.0, JavaFX has been programmed in Java itself and
provides a comprehensive API. JavaFX also supports FXML, which can be (but is not required to be) used to specify the user interface. JavaFX has been bundled with Java since JDK 7, update 4. At the time of this writing, the latest version of JavaFX is JavaFX 9, which is bundled with JDK 9. As such, it is the version of JavaFX discussed here.

NOTE This and the following two chapters assume that you have a basic understanding of event handling as introduced in Chapter 24, and Swing fundamentals, as described by the preceding three chapters.

JavaFX Basic Concepts

In general, the JavaFX framework has all of the good features of Swing. For example, JavaFX is lightweight. It can also support an MVC architecture. Much of what you already know about creating GUIs using Swing is conceptually applicable to JavaFX. That said, there are significant differences between the two.

From a programmer’s point of view, the first differences you notice between JavaFX and Swing are the organization of the framework and the relationship of the main components. Simply put, JavaFX offers a more streamlined, easier-to-use, updated approach. JavaFX also greatly simplifies the rendering of objects because it handles repainting automatically. It is no longer necessary for your program to handle this task manually. The preceding is not intended to imply that Swing is poorly designed. It is not. It is just that the art and science of programming has moved forward, and JavaFX has received the benefits of that evolution. Simply put, JavaFX facilitates a more visually dynamic approach to GUIs.

The JavaFX Packages

The JavaFX elements are contained in packages that begin with the javafx prefix. At the time of this writing, there are more than 30 JavaFX packages in its API library. Here are four examples: javafx.application, javafx.stage, javafx.scene, and javafx.scene.layout. Although we will only use a few of these packages in this chapter, you will want to spend some time browsing their capabilities. JavaFX offers a wide array of functionality. Beginning with JDK 9, the JavaFX packages are organized into modules, such as javafx.base, javafx.graphics, and javafx.controls.

The Stage and Scene Classes

The central metaphor implemented by JavaFX is the stage. As in the case of an actual stage play, a stage contains a scene. Thus, loosely speaking, a stage defines a
space and a scene defines what goes in that space. Or, put another way, a stage is a container for scenes and a scene is a container for the items that comprise the scene. As a result, all JavaFX applications have at least one stage and one scene. These elements are encapsulated in the JavaFX API by the Stage and Scene classes. To create a JavaFX application, you will, at minimum, add at least one Scene object to a Stage. Let’s look a bit more closely at these two classes.

**Stage** is a top-level container. All JavaFX applications automatically have access to one Stage, called the *primary stage*. The primary stage is supplied by the run-time system when a JavaFX application is started. Although you can create other stages, for many applications, the primary stage will be the only one required.

As mentioned, **Scene** is a container for the items that comprise the scene. These can consist of controls, such as push buttons and check boxes, text, and graphics. To create a scene, you will add those elements to an instance of Scene.

### Nodes and Scene Graphs

The individual elements of a scene are called *nodes*. For example, a push button control is a node. However, nodes can also consist of groups of nodes. Furthermore, a node can have a child node. In this case, a node with a child is called a *parent node* or *branch node*. Nodes without children are terminal nodes and are called leaves. The collection of all nodes in a scene creates what is referred to as a *scene graph*, which comprises a *tree*.

There is one special type of node in the scene graph, called the *root node*. This is the top-level node and is the only node in the scene graph that does not have a parent. Thus, with the exception of the root node, all other nodes have parents, and all nodes either directly or indirectly descend from the root node.

The base class for all nodes is **Node**. There are several other classes that are, either directly or indirectly, subclasses of **Node**. These include **Parent**, **Group**, **Region**, and **Control**, to name a few.

### Layouts

JavaFX provides several layout panes that manage the process of placing elements in a scene. For example, the **FlowPane** class provides a flow layout and the **GridPane** class supports a row/column grid-based layout. Several other layouts, such as **BorderPane** (which is similar to the AWT’s **BorderLayout**), are available. The layout panes are packaged in **javafx.scene.layout**.

### The Application Class and the Life-cycle Methods
A JavaFX application must be a subclass of the **Application** class, which is packaged in **javafx.application**. Thus, your application class will extend **Application**. The **Application** class defines three life-cycle methods that your application can override. These are called **init()**, **start()**, and **stop()**, and are shown here, in the order in which they are called:

```java
void init()
abstract void start(Stage primaryStage)
void stop()
```

The **init()** method is called when the application begins execution. It is used to perform various initializations. As will be explained, however, it **cannot** be used to create a stage or build a scene. If no initializations are required, this method need not be overridden because an empty, default version is provided.

The **start()** method is called after **init()**. This is where your application begins and it **can** be used to construct and set the scene. Notice that it is passed a reference to a **Stage** object. This is the stage provided by the run-time system and is the primary stage. (You can also create other stages, but you won’t need to for simple applications.) Notice that this method is abstract. Thus, it must be overridden by your application.

When your application is terminated, the **stop()** method is called. It is here that you can handle any cleanup or shutdown chores. In cases in which no such actions are needed, an empty, default version is provided.

One other point: For a modular JavaFX application, the package that contains your main application class (that is, your subclass of **Application**) must be exported by its module so that it can be found by the **javafx.graphics** module.

**Launching a JavaFX Application**

To start a free-standing JavaFX application, you must call the **launch()** method defined by **Application**. It has two forms. Here is the one used in this chapter:

```java
public static void launch(String … args)
```

Here, **args** is a possibly empty list of strings that typically specify command-line arguments. When called, **launch()** causes the application to be constructed, followed by calls to **init()** and **start()**. The **launch()** method will not return until after the application has terminated. This version of **launch()** starts the subclass of **Application** from which **launch()** is called. The second form of **launch()** lets you specify a class other than the enclosing class to start.
Before moving on, it is necessary to make an important point: JavaFX applications that have been packaged by using the `javafxpackager` tool (or its equivalent in an IDE) do not need to include a call to `launch()`. However, its inclusion often simplifies the test/debug cycle, and it lets the program be used without the creation of a JAR file. Thus, it is included in all of the JavaFX programs in this book.

### A JavaFX Application Skeleton

All JavaFX applications share the same basic skeleton. Therefore, before looking at any more JavaFX features, it will be useful to see what that skeleton looks like. In addition to showing the general form of a JavaFX application, the skeleton also illustrates how to launch the application and demonstrates when the life-cycle methods are called. A message noting when each life-cycle method is called is displayed on the console. The complete skeleton is shown here:

```java
// A JavaFX application skeleton.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;

public class JavaFXSkel extends Application {

    public static void main(String[] args) {

        System.out.println("Launching JavaFX application.");

        // Start the JavaFX application by calling launch().
        launch(args);
    }
}
```
// Override the init() method.
public void init() {
    System.out.println("Inside the init() method.");
}

// Override the start() method.
public void start(Stage myStage) {

    System.out.println("Inside the start() method.");

    // Give the stage a title.
    myStage.setTitle("JavaFX Skeleton.");

    // Create a root node. In this case, a flow layout pane
    // is used, but several alternatives exist.
    FlowPane rootNode = new FlowPane();

    // Create a scene.
    Scene myScene = new Scene(rootNode, 300, 200);

    // Set the scene on the stage.
    myStage.setScene(myScene);

    // Show the stage and its scene.
    myStage.show();
}

// Override the stop() method.
public void stop() {
    System.out.println("Inside the stop() method.");
}
}

Although the skeleton is quite short, it can be compiled and run. It produces the empty window shown here. (The precise look of the frame may vary slightly, based on your execution environment.)
It also produces the following output on the console:

```
Launching JavaFX application.
Inside the init() method.
Inside the start() method.
```

When you close the window, this message is displayed on the console:

```
Inside the stop() method.
```

Of course, in a real program, the life-cycle methods would not normally output anything to `System.out`. They do so here simply to illustrate when each method is called. Furthermore, as explained earlier, you will need to override the `init()` and `stop()` methods only if your application must perform special startup or shutdown actions. Otherwise, you can use the default implementations of these methods provided by the `Application` class.

Let’s examine this program in detail. It begins by importing four packages. The first is `javafx.application`, which contains the `Application` class. The `Scene` class is packaged in `javafx.scene`, and `Stage` is packaged in `javafx.stage`. The `javafx.scene.layout` package provides several layout panes. The one used by the program is `FlowPane`.

Next, the application class `JavaFXSkel` is created. Notice that it extends `Application`. As explained, `Application` is the class from which all JavaFX applications are derived. `JavaFXSkel` contains two methods. The first is `main()`. It is used to launch the application via a call to `launch()`. Notice that the `args` parameter to `main()` is passed to the `launch()` method. Although this is a common approach, you can pass a different set of parameters to `launch()`, or none at all. One other point: As explained earlier, `launch()` is required by a free-standing application, but not in other cases. When it is not needed, `main()` is also not needed. However, for reasons already explained, both `main()` and `launch()` are included in the JavaFX
When the application begins, the `init()` method is called first by the JavaFX run-time system. For the sake of illustration, it simply displays a message on `System.out`, but it would normally be used to initialize some aspect of the application. Of course, if no initialization is required, it is not necessary to override `init()` because an empty, default implementation is provided. It is important to emphasize that `init()` cannot be used to create the stage or scene portions of a GUI. Rather, these items should be constructed and displayed by the `start()` method.

After `init()` finishes, the `start()` method executes. It is here that the initial scene is created and set to the primary stage. Let’s look at this method line-by-line. First, notice that `start()` has a parameter of type `Stage`. When `start()` is called, this parameter will receive a reference to the primary stage of the application. It is to this stage that you will set a scene for the application.

After displaying a message on the console that `start()` has begun execution, it sets the title of the stage using this call to `setTitle()`:

```java
myStage.setTitle("JavaFX Skeleton.");
```

Although this step is not necessarily required, it is customary for stand-alone applications. This title becomes the name of the main application window.

Next, a root node for a scene is created. The root node is the only node in a scene graph that does not have a parent. In this case, a `FlowPane` is used for the root node, but there are several other classes that can be used for the root.

```java
FlowPane rootNode = new FlowPane();
```

As mentioned, a `FlowPane` uses a flow layout. This is a layout in which elements are positioned line-by-line, with lines wrapping as needed. (Thus, it works much like the `FlowLayout` class used by the AWT and Swing.) In this case, a horizontal flow is used, but it is possible to specify a vertical flow. Although not needed by this skeletal application, it is also possible to specify other layout properties, such as a vertical and horizontal gap between elements, and an alignment. You will see an example of this later in this chapter.

The following line uses the root node to construct a `Scene`:

```java
Scene myScene = new Scene(rootNode, 300, 200);
```

`Scene` provides several versions of its constructor. The one used here creates a scene that has the specified root with the specified width and height. It is shown here:

```java
Scene(Parent rootnode, double width, double height)
```
Notice that the type of **rootnode** is **Parent**. It is a subclass of **Node** and encapsulates nodes that can have children. Also notice that the width and the height are **double** values. This lets you pass fractional values, if needed. In the skeleton, the root is **rootNode**, the width is 300 and the height is 200.

The next line in the program sets **myScene** as the scene for **myStage**:

```java
myStage.setScene(myScene);
```

Here, **setScene()** is a method defined by **Stage** that sets the scene to that specified by its argument.

In cases in which you don’t make further use of the scene, you can combine the previous two steps, as shown here:

```java
myStage.setScene(new Scene(rootNode, 300, 200));
```

Because of its compactness, this form will be used by most of the subsequent examples.

The last line in **start()** displays the stage and its scene:

```java
myStage.show();
```

In essence, **show()** shows the window that was created by the stage and scene.

When you close the application, its window is removed from the screen and the **stop()** method is called by the JavaFX run-time system. In this case, **stop()** simply displays a message on the console, illustrating when it is called. However, **stop()** would not normally display anything. Furthermore, if your application does not need to handle any shutdown actions, there is no reason to override **stop()** because an empty, default implementation is provided.

### Compiling and Running a JavaFX Program

One important advantage of JavaFX is that the same program can be run in a variety of different execution environments. For example, you can run a JavaFX program as a stand-alone desktop application or as a Java Web Start application. However, different ancillary files may be needed in some cases, for example, an HTML file or a Java Network Launch Protocol (JNLP) file.

In general, a JavaFX program is compiled like any other Java program. However, because of the need for additional support for various execution environments, the easiest way to compile a JavaFX application is to use an Integrated Development Environment (IDE) that fully supports JavaFX programming, such as NetBeans. Just follow the instructions for the IDE you are using.
Alternatively, if you want to compile and test a JavaFX application using the command-line tools, you can easily do so. Just compile and run the application in the normal way, using `javac` and `java`. Be aware that using the command-line compiler neither creates any HTML or JNLP files that would be needed if you want to run the application in a way other than as a stand-alone application, nor does it create a JAR file for the program. To create these files, you need to use a tool such as `javafxpackager`.

**The Application Thread**

In the preceding discussion, it was mentioned that you cannot use the `init()` method to construct a stage or scene. You also cannot create these items inside the application’s constructor. The reason is that a stage or scene must be constructed on the *application thread*. However, the application’s constructor and the `init()` method are called on the main thread, also called the *launcher thread*. Thus, they can’t be used to construct a stage or scene. Instead, you must use the `start()` method, as the skeleton demonstrates, to create the initial GUI because `start()` is called on the application thread.

Furthermore, any changes to the GUI currently displayed must be made from the application thread. Fortunately, in JavaFX, events are sent to your program on the application thread. Therefore, event handlers can be used to interact with the GUI. The `stop()` method is also called on the application thread.

**A Simple JavaFX Control: Label**

The primary ingredient in most user interfaces is the control because a control enables the user to interact with the application. As you would expect, JavaFX supplies a rich assortment of controls. The simplest control is the label because it just displays a message, which, in this example, is text. Although quite easy to use, the label is a good way to introduce the techniques needed to begin building a scene graph.

The JavaFX label is an instance of the `Label` class, which is packaged in `javafx.scene.control`. `Label` inherits `Labeled` and `Control`, among other classes. The `Labeled` class defines several features that are common to all labeled elements (that is, those that can contain text), and `Control` defines features related to all controls.

`Label` defines three constructors. The one we will use here is

```java
Label(String str)
```
Here, \( str \) is the string that is displayed.

Once you have created a label (or any other control), it must be added to the scene’s content, which means adding it to the scene graph. To do this, you will first call \texttt{getChildren()} on the root node of the scene graph. It returns a list of the child nodes in the form of an \texttt{ObservableList<Node>}. \texttt{ObservableList} is packaged in \texttt{javafx.collections}, and it inherits \texttt{java.util.List}, which means that it supports all of the features available to a list as defined by the Collections Framework. Using the returned list of child nodes, you can add the label to the list by calling \texttt{add()}, passing in a reference to the label.

The following program puts the preceding discussion into action by creating a simple JavaFX application that displays a label:
// Demonstrate a JavaFX label.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;

public class JavaFXLabelDemo extends Application {

    public static void main(String[] args) {

        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate a JavaFX label.");

        // Use a FlowPane for the root node.
        FlowPane rootNode = new FlowPane();

        // Create a scene.
        Scene myScene = new Scene(rootNode, 300, 200);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        // Create a label.
        Label myLabel = new Label("This is a JavaFX label");

        // Add the label to the scene graph.
        rootNode.getChildren().add(myLabel);

        // Show the stage and its scene.
        myStage.show();
    }
}

This program produces the following window:
In the program, pay special attention to this line:

```java
rootNode.getChildren().add(myLabel);
```

It adds the label to the list of children for which `rootNode` is the parent. Although this line could be separated into its individual pieces if necessary, you will often see it as shown here.

Before moving on, it is useful to point out that `ObservableList` provides a method called `addAll()` that can be used to add two or more children to the scene graph in a single call. (You will see an example of this shortly.) To remove a control from the scene graph, call `remove()` on the `ObservableList`. For example,

```java
rootNode.getChildren().remove(myLabel);
```

removes `myLabel` from the scene.

**Using Buttons and Events**

Although the program in the preceding section presents a simple example of using a JavaFX control and constructing a scene graph, it does not show how to handle events. As you know, most GUI controls generate events that are handled by your program. For example, buttons, check boxes, and lists all generate events when they are used. In many ways, event handling in JavaFX is similar to event handling in Swing or the AWT, but it’s more streamlined. Therefore, if you already are proficient at handling events for these other two GUIs, you will have no trouble using the event handling system provided by JavaFX.

One commonly used control is the button. This makes button events one of the most frequently handled. Therefore, a button is a good way to demonstrate the fundamentals of event handling in JavaFX. For this reason, the fundamentals of
event handling and the button are introduced together.

**Event Basics**

The base class for JavaFX events is the `Event` class, which is packaged in `javafx.event`. `Event` inherits `java.util.EventObject`, which means that JavaFX events share the same basic functionality as other Java events. Several subclasses of `Event` are defined. The one that we will use here is `ActionEvent`. It handles action events generated by a button.

In general, JavaFX uses what is, in essence, the delegation event model approach to event handling. To handle an event, you must first register the handler that acts as a listener for the event. When the event occurs, the listener is called. It must then respond to the event and return. In this regard, JavaFX events are managed much like Swing events, for example.

Events are handled by implementing the `EventHandler` interface, which is also in `javafx.event`. It is a generic interface with the following form:

interface EventHandler<T extends Event>

Here, `T` specifies the type of event that the handler will handle. It defines one method, called `handle()`, which receives the event object as a parameter. It is shown here:

```java
void handle(T eventObj)
```

Here, `eventObj` is the event that was generated. Typically, event handlers are implemented through anonymous inner classes or lambda expressions, but you can use stand-alone classes for this purpose if it is more appropriate to your application (for example, if one event handler will handle events from more than one source).

Although not required by the examples in this chapter, it is sometimes useful to know the source of an event. This is especially true if you are using one handler to handle events from different sources. You can obtain the source of the event by calling `getSource()`, which is inherited from `java.util.EventObject`. It is shown here:

```java
Object getSource()
```

Other methods in `Event` let you obtain the event type, determine if the event has been consumed, consume an event, fire an event, and obtain the target of the event. When an event is consumed, it stops the event from being passed to a parent handler.
One last point: In JavaFX, events are processed via an event dispatch chain. When an event is generated, it is passed to the root node of the chain. The event is then passed down the chain to the target of the event. After the target node processes the event, the event is passed back up the chain, thus allowing parent nodes a chance to process the event, if necessary. This is called event bubbling. It is possible for a node in the chain to consume an event, which prevents it from being further processed.

NOTE Although not used in this introduction to JavaFX, an application can also implement an event filter, which can be used to manage events. A filter is added to a node by calling addEventFilter(), which is defined by Node. A filter can consume an event, thus preventing further processing.

Introducing the Button Control

In JavaFX, the push button control is provided by the Button class, which is in javafx.scene.control. Button inherits a fairly long list of base classes that include ButtonBase, Labeled, Region, Control, Parent, and Node. If you examine the API documentation for Button, you will see that much of its functionality comes from its base classes. Furthermore, it supports a wide array of options. However, here we will use its default form. Buttons can contain text, graphics, or both. In this chapter, we will use text-based buttons. An example of a graphics-based button is shown in the next chapter.

Button defines three constructors. The one we will use is shown here:

Button(String str)

In this case, str is the message that is displayed in the button.

When a button is pressed, an ActionEvent is generated. ActionEvent is packaged in javafx.event. You can register a listener for this event by using setOnAction(), which has this general form:

final void setOnAction(EventHandler<ActionEvent> handler)

Here, handler is the handler being registered. As mentioned, often you will use an anonymous inner class or lambda expression for the handler. The setOnAction() method sets the property onAction, which stores a reference to the handler. As with all other Java event handling, your handler must respond to the event as fast as possible and then return. If your handler consumes too much time, it will noticeably slow down the application. For lengthy operations, you must use a separate thread of
Demonstrating Event Handling and the Button

The following program demonstrates event handling. It uses two buttons and a label. Each time a button is pressed, the label is set to display which button was pressed.

```java
// Demonstrate JavaFX events and buttons.
import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;

public class JavaFXEventDemo extends Application {

    Label response;

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {
        // Give the stage a title.
        myStage.setTitle("Demonstrate JavaFX Buttons and Events.");
    }
}
```
// Use a FlowPane for the root node. In this case, 
// vertical and horizontal gaps of 10.
FlowPane rootNode = new FlowPane(10, 10);

// Center the controls in the scene.
rootNode.setAlignment(Pos.CENTER);

// Create a scene.
Scene myScene = new Scene(rootNode, 300, 100);

// Set the scene on the stage.
myStage.setScene(myScene);

// Create a label.
response = new Label("Push a Button");

// Create two push buttons.
Button btnAlpha = new Button("Alpha");
Button btnBeta = new Button("Beta");

// Handle the action events for the Alpha button.
btnAlpha.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        response.setText("Alpha was pressed.");
    }
});

// Handle the action events for the Beta button.
btnBeta.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        response.setText("Beta was pressed.");
    }
});

// Add the label and buttons to the scene graph.
rootNode.getChildren().addAll(btnAlpha, btnBeta, response);

// Show the stage and its scene.
myStage.show();}
Let's examine a few key portions of this program. First, notice how buttons are created by these two lines:

```java
Button btnAlpha = new Button("Alpha");
Button btnBeta = new Button("Beta");
```

This creates two text-based buttons. The first displays the string Alpha; the second displays Beta.

Next, an action event handler is set for each of these buttons. The sequence for the Alpha button is shown here:

```java
// Handle the action events for the Alpha button.
btnAlpha.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        response.setText("Alpha was pressed.");
    }
});
```

As explained, buttons respond to events of type `ActionEvent`. To register a handler for these events, the `setOnAction()` method is called on the button. It uses an anonymous inner class to implement the `EventHandler` interface. (Recall that `EventHandler` defines only the `handle()` method.) Inside `handle()`, the text in the `response` label is set to reflect the fact that the Alpha button was pressed. Notice that this is done by calling the `setText()` method on the label. Events are handled by the Beta button in the same way.

After the event handlers have been set, the `response` label and the buttons `btnAlpha` and `btnBeta` are added to the scene graph by using a call to `addAll()`:

```java
rootNode.getChildren().addAll(btnAlpha, btnBeta, response);
```

The `addAll()` method adds a list of nodes to the invoking parent node. Of course, these nodes could have been added by three separate calls to `add()`, but the `addAll()` method is more convenient to use in this situation.

There are two other things of interest in this program that relate to the way the controls are displayed in the window. First, when the root node is created, this
statement is used:

```java
FlowPane rootNode = new FlowPane(10, 10);
```

Here, the `FlowPane` constructor is passed two values. These specify the horizontal and vertical gap that will be left around elements in the scene. If these gaps are not specified, then two elements (such as two buttons) would be positioned in such a way that no space is between them. Thus, the controls would run together, creating a very unappealing user interface. Specifying gaps prevents this.

The second point of interest is the following line, which sets the alignment of the elements in the `FlowPane`:

```java
rootNode.setAlignment(Pos.CENTER);
```

Here, the alignment of the elements is centered. This is done by calling `setAlignment()` on the `FlowPane`. The value `Pos.CENTER` specifies that both a vertical and horizontal center will be used. Other alignments are possible. `Pos` is an enumeration that specifies alignment constants. It is packaged in `javafx.geometry`.

Before moving on, one more point needs to be made. The preceding program used anonymous inner classes to handle button events. However, because the `EventHandler` interface defines only one abstract method, `handle()`, a lambda expression could have passed to `setOnAction()`, instead. In this case, the parameter type of `setOnAction()` would supply the target context for the lambda expression. For example, here is the handler for the Alpha button, rewritten to use a lambda:

```java
btnAlpha.setOnAction(ae ->
    response.setText("Alpha was pressed."));
```

Notice that the lambda expression is more compact than the anonymous inner class. Because lambda expressions are a relatively new feature but the anonymous inner class is a widely used construct, readily understood by nearly all Java programmers, the event handlers in subsequent examples will use anonymous inner classes. This will also allow the examples to be compiled by readers using JDK 7 (which does not support lambdas). However, on your own, you might want to experiment with converting them to lambda expressions. It is a good way to gain experience using lambdas in your own code.

**Drawing Directly on a Canvas**

As mentioned early on, JavaFX handles rendering tasks for you automatically, rather
than you handling them manually. This is one of the most important ways that JavaFX improves on Swing. As you may know, in Swing or the AWT, you must call the `repaint()` method to cause a window to be repainted. Furthermore, your application needs to store the window contents, redrawing them when painting is requested. JavaFX eliminates this tedious mechanism because it keeps track of what you display in a scene and redispays that scene as needed. This is called *retained mode*. With this approach, there is no need to call a method like `repaint()`. Rendering is automatic.

One place that JavaFX’s approach to rendering is especially helpful is when displaying graphics objects, such as lines, circles, and rectangles. JavaFX’s graphics methods are found in the `GraphicsContext` class, which is part of `javafx.scene.canvas`. These methods can be used to draw directly on the surface of a canvas, which is encapsulated by the `Canvas` class in `javafx.scene.canvas`. When you draw something, such as a line, on a canvas, JavaFX automatically renders it whenever it needs to be redisplayed.

Before you can draw on a canvas, you must perform two steps. First, you must create a `Canvas` instance. Second, you must obtain a `GraphicsContext` object that refers to that canvas. You can then use the `GraphicsContext` to draw output on the canvas.

The `Canvas` class is derived from `Node`; thus it can be used as a node in a scene graph. `Canvas` defines two constructors. One is the default constructor, and the other is the one shown here:

```java
Canvas(double width, double height)
```

Here, `width` and `height` specify the dimensions of the canvas.

To obtain a `GraphicsContext` that refers to a canvas, call `getGraphicsContext2D()`. Here is its general form:

```java
GraphicsContext getGraphicsContext2D()
```

The graphics context for the canvas is returned.

`GraphicsContext` defines a large number of methods that draw shapes, text, and images, and support effects and transforms. If sophisticated graphics programming is in your future, you will definitely want to study its capabilities closely. For our purposes, we will use only a few of its methods, but they will give you a sense of its power. They are described here.

You can draw a line using `strokeLine()`, shown here:

```java
void strokeLine(double startX, double startY, double endX, double endY)
```
It draws a line from $startX, startY$ to $endX, endY$, using the current stroke, which can be a solid color or some more complex style.

To draw a rectangle, use either `strokeRect()` or `fillRect()`, shown here:

```java
void strokeRect(double topX, double topY, double width, double height)
void fillRect(double topX, double topY, double width, double height)
```

The upper-left corner of the rectangle is at $topX, topY$. The `width` and `height` parameters specify its width and height. The `strokeRect()` method draws the outline of a rectangle using the current stroke, and `fillRect()` fills the rectangle with the current fill. The current fill can be as simple as a solid color or something more complex.

To draw an ellipse, use either `strokeOval()` or `fillOval()`, shown next:

```java
void strokeOval(double topX, double topY, double width, double height)
void fillOval(double topX, double topY, double width, double height)
```

The upper-left corner of the rectangle that bounds the ellipse is at $topX, topY$. The `width` and `height` parameters specify its width and height. The `strokeOval()` method draws the outline of an ellipse using the current stroke, and `fillOval()` fills the oval with the current fill. To draw a circle, pass the same value for `width` and `height`.

You can draw text on a canvas by using the `strokeText()` and `fillText()` methods. We will use this version of `fillText()`:

```java
void fillText(String str, double topX, double topY)
```

It displays `str` starting at the location specified by $topX, topY$, filling the text with the current fill.

You can set the font and font size of the text being displayed by using `setFont()`. You can obtain the font used by the canvas by calling `getFont()`. By default, the system font is used. You can create a new font by constructing a `Font` object. `Font` is packaged in `javax.scene.text`. For example, you can create a default font of a specified size by using this constructor:

```java
Font(double fontSize)
```

Here, `fontSize` specifies the size of the font.

You can specify the fill and stroke using these two methods defined by `GrahpicsContext`:
void setFill(Paint newFill)
void setStroke(Paint newStroke)

Notice that the parameter of both methods is of type Paint. This is an abstract class packaged in javafx.scene.paint. Its subclasses define fills and strokes. The one we will use is Color, which simply describes a solid color. Color defines several static fields that specify a wide array of colors, such as Color.BLUE, Color.RED, Color.GREEN, and so on.

The following program uses the aforementioned methods to demonstrate drawing on a canvas. It first displays a few graphic objects on the canvas. Then, each time the Change Color button is pressed, the color of three of the objects changes color. If you run the program, you will see that the shapes whose color is not changed are unaffected by the change in color of the other objects. Furthermore, if you try covering and then uncovering the window, you will see that the canvas is automatically repainted, without any other actions on the part of your program. Sample output is shown here:
/ Demonstrate drawing.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;
import javafx.scene.shape.*;
import javafx.scene.canvas.*;
import javafx.scene.paint.*;
import javafx.scene.text.*;

public class DirectDrawDemo extends Application {

    GraphicsContext gc;

    Color[] colors = { Color.RED, Color.BLUE, Color.GREEN, Color.BLACK};
    int colorIdx = 0;

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Draw Directly to a Canvas.");

        // Use a FlowPane for the root node.
        FlowPane rootNode = new FlowPane();

        // Center the nodes in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 450, 450);

        // Set the scene on the stage.
        myStage.setScene(myScene);

It is important to emphasize that **GraphicsContext** supports many more operations than those demonstrated by the preceding program. For example, you can apply various transforms, rotations, and effects. Despite its power, its various features are easy to master and use. One other point: A canvas is transparent. Therefore, if you stack canvases, the contents of both will show. This may be useful in some situations.

**NOTE** **javafx.scene.shape** contains several classes that can also be used to draw various types of graphical shapes, such as circles, arcs, and lines. These are represented by nodes and can, therefore, be directly part of the scene graph. You will want to explore these on your own.
Exploring JavaFX Controls

The previous chapter described several of the core concepts relating to the JavaFX GUI framework. In the process, it introduced two controls: the label and the button. This chapter continues the discussion of JavaFX controls. It begins by describing how to include images in a label and button. It then presents an overview of several more JavaFX controls, including check boxes, lists, and trees. Keep in mind that JavaFX is a rich and powerful framework. The purpose of this chapter is to introduce a representative sampling of the JavaFX controls and to describe several common techniques. Once you understand the basics, you will be able to easily learn the other controls.

The JavaFX control classes discussed in this chapter are shown here:

<table>
<thead>
<tr>
<th>Button</th>
<th>ListView</th>
<th>TextField</th>
</tr>
</thead>
<tbody>
<tr>
<td>CheckBox</td>
<td>RadioButton</td>
<td>ToggleButton</td>
</tr>
<tr>
<td>Label</td>
<td>ScrollPane</td>
<td>TreeView</td>
</tr>
</tbody>
</table>

These and the other JavaFX controls are packaged in `javafx.scene.control`.

Also discussed are the `Image` and `ImageView` classes, which provide support for images in controls; `Tooltip`, which is used to add tooltips to a control; as well as various effects and transforms.

Using Image and ImageView

Several of JavaFX’s controls let you include an image. For example, in addition to text, you can specify an image in a label or a button. Furthermore, you can embed stand-alone images in a scene directly. At the foundation for JavaFX’s support for images are two classes: `Image` and `ImageView`. `Image` encapsulates the image, itself, and `ImageView` manages the display of an image. Both classes are packaged in `javafx.scene.image`.

The `Image` class loads an image from either an `InputStream`, a URL, or a path to the image file. `Image` defines several constructors; this is the one we will use:

```
Image(String url)
```
Here, *url* specifies a URL or a path to a file that supplies the image. The argument is assumed to refer to a path if it does not constitute a properly formed URL. Otherwise, the image is loaded from the URL. The examples that follow will load images from files on the local file system. Other constructors let you specify various options, such as the image’s width and height. One other point: *Image* is not derived from *Node*. Thus, it cannot, itself, be part of a scene graph.

Once you have an *Image*, you will use *ImageView* to display it. *ImageView* is derived from *Node*, which means that it can be part of a scene graph. *ImageView* defines three constructors. The first one we will use is shown here:

```
ImageView(Image image)
```

This constructor creates an *ImageView* that uses *image* for its image.

Putting the preceding discussion into action, here is a program that loads an image of an hourglass and displays it via *ImageView*. The hourglass image is contained in a file called *hourglass.png*, which is assumed to be in the local directory.
// Load and display an image.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.geometry.*;
import javafx.scene.image.*;

public class ImageDemo extends Application {

    public static void main(String[] args) {

        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Display an Image");

        // Use a FlowPane for the root node.
        FlowPane rootNode = new FlowPane();

        // Use center alignment.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 300, 200);
    }
}
Sample output from the program is shown here:

In the program, pay close attention to the following sequence that loads the image and then creates an `ImageView` that uses that image:

```java
// Create an image.
Image hourglass = new Image("HourGlass.png");

// Create an image view that uses the image.
ImageView hourglassIV = new ImageView(hourglass);
```

As explained, an image by itself cannot be added to the scene graph. It must first be embedded in an `ImageView`.

In cases in which you won’t make further use of the image, you can specify a
URL or filename when creating an **ImageView**. In this case, there is no need to explicitly create an **Image**. Instead, an **image** instance containing the specified image is constructed automatically and embedded in the **ImageView**. Here is the **ImageView** constructor that does this:

```
ImageView(String url)
```

Here, `url` specifies the URL or the path to a file that contains the image.

**Adding an Image to a Label**

As explained in the previous chapter, the **Label** class encapsulates a label. It can display a text message, a graphic, or both. So far, we have used it to display only text, but it is easy to add an image. To do so, use this form of **Label**’s constructor:

```
Label(String str, Node image)
```

Here, `str` specifies the text message and `image` specifies the image. Notice that the image is of type **Node**. This allows great flexibility in the type of image added to the label, but for our purposes, the image type will be **ImageView**.

Here is a program that demonstrates a label that includes a graphic. It creates a label that displays the string "Hourglass" and shows the image of an hourglass that is loaded from the **hourglass.png** file.
// Demonstrate an image in a label.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.geometry.*;
import javafx.scene.image.*;

public class LabelImageDemo extends Application {

    public static void main(String[] args) {

        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Use an Image in a Label");

        // Use a FlowPane for the root node.
        FlowPane rootNode = new FlowPane();

        // Use center alignment.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 300, 200);

        // Set the scene on the stage.
        myStage.setScene(myScene);
    }
}
// Create an ImageView that contains the specified image.
ImageView hourglassIV = new ImageView("hourglass.png");

// Create a label that contains both an image and text.
Label hourglassLabel = new Label("Hourglass", hourglassIV);

// Add the label to the scene graph.
rootNode.getChildren().add(hourglassLabel);

// Show the stage and its scene.
myStage.show();
}

Here is the window produced by the program:

![Image of Hourglass Label]

As you can see, both the image and the text are displayed. Notice that the text is to the right of the image. This is the default. You can change the relative positions of the image and text by calling `setContentDisplay()` on the label. It is shown here:

```java
final void setContentDisplay(ContentDisplay position)
```

The value passed to `position` determines how the text and image is displayed. It must be one of these values, which are defined by the `ContentDisplay` enumeration:

<table>
<thead>
<tr>
<th>BOTTOM</th>
<th>RIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CENTER</td>
<td>TEXT_ONLY</td>
</tr>
<tr>
<td>GRAPHIC_ONLY</td>
<td>TOP</td>
</tr>
<tr>
<td>LEFT</td>
<td></td>
</tr>
</tbody>
</table>
With the exception of TEXT_ONLY and GRAPHIC_ONLY, the values specify the location of the image. For example, if you add this line to the preceding program:

```java
hourglassLabel.setContentDisplay(ContentDisplay.TOP);
```

the image of the hourglass will be above the text, as shown here:

![Image of hourglass](image.png)

The other two values let you display either just the text or just the image. This might be useful if your application wants to use an image at some times, and not at others, for example. (If you want only an image, you can simply display it without using a label, as described in the previous section.)

You can also add an image to a label after it has been constructed by using the `setGraphic()` method. It is shown here:

```java
final void setGraphic(Node image)
```

Here, `image` specifies the image to add.

## Using an Image with a Button

**Button** is JavaFX’s class for push buttons. The preceding chapter introduced the **Button** class. There, you saw an example of a button that contained text. Although such buttons are common, you are not limited to this approach because you can include an image. You can also use only the image if you choose. The procedure for adding an image to a button is similar to that used to add an image to a label. First obtain an **ImageView** of the image. Then add it to the button. One way to add the image is to use this constructor:

```java
Button(String str, Node image)
```
Here, \textit{str} specifies the text that is displayed within the button and \textit{image} specifies the image. You can specify the position of the image relative to the text by using \texttt{setContentDisplay()} in the same way as just described for \texttt{Label}.

Here is an example that displays two buttons that contain images. The first shows an hourglass. The second shows an analog clock. When a button is pressed, the selected timepiece is reported. Notice that the text is displayed beneath the image.

```java
// Use an image with a button.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;
import javafx.scene.image.*;

public class ButtonImageDemo extends Application {

  Label response;

  public static void main(String[] args) {

    // Start the JavaFX application by calling launch().
    launch(args);
  }

  // Override the start() method.
  public void start(Stage myStage) {

    // Give the stage a title.
    myStage.setTitle("Use Images with Buttons");

    // Use a FlowPane for the root node. In this case,
    // vertical and horizontal gaps of 10.
    FlowPane rootNode = new FlowPane(10, 10);

    // Center the controls in the scene.
    rootNode.setAlignment(Pos.CENTER);
  }
}
```
// Create a scene.
Scene myScene = new Scene(rootNode, 250, 450);

// Set the scene on the stage.
myStage.setScene(myScene);

// Create a label.
response = new Label("Push a Button");

// Create two image-based buttons.
Button btnHourglass = new Button("Hourglass",
       new ImageView("hourglass.png");
Button btnAnalogClock = new Button("Analog Clock",
       new ImageView("analog.png");

// Position the text under the image.
btnHourglass.setContentDisplay(ContentDisplay.TOP);
btnAnalogClock.setContentDisplay(ContentDisplay.TOP);

// Handle the action events for the hourglass button.
btnHourglass.setOnAction(new EventHandler<ActionEvent>() {
       public void handle(ActionEvent ae) {
       response.setText("Hourglass Pressed");
       }
});

// Handle the action events for the analog clock button.
btnAnalogClock.setOnAction(new EventHandler<ActionEvent>() {
       public void handle(ActionEvent ae) {
       response.setText("Analog Clock Pressed");
       }
});

// Add the label and buttons to the scene graph.
rootNode.getChildren().addAll(btnHourglass, btnAnalogClock, response);

// Show the stage and its scene.
myStage.show();

The output produced by this program is shown here:
If you want a button that contains only the image, pass a null string for the text when constructing the button and then call `setContentDisplay()`, passing in the parameter `ContentDisplay.GRAPHICONLY`. For example, if you make these modifications to the previous program, the output will look like this:
ToggleButton

A useful variation on the push button is called the toggle button. A toggle button looks just like a push button, but it acts differently because it has two states: pushed and released. That is, when you press a toggle button, it stays pressed rather than popping back up as a regular push button does. When you press the toggle button a second time, it releases (pops up). Therefore, each time a toggle button is pushed, it toggles between these two states. In JavaFX, a toggle button is encapsulated in the ToggleButton class. Like Button, ToggleButton is also derived from ButtonBase. It implements the Toggle interface, which defines functionality common to all types of two-state buttons.

ToggleButton defines three constructors. This is the one we will use:

ToggleButton(String str)

Here, str is the text displayed in the button. Another constructor allows you to
include an image. Like other buttons, a **ToggleButton** generates an action event when it is pressed.

Because **ToggleButton** defines a two-state control, it is commonly used to let the user select an option. When the button is pressed, the option is selected. When the button is released, the option is deselected. For this reason, a program usually needs to determine the toggle button’s state. To do this, use the **isSelected( )** method, shown here:

```java
final boolean isSelected( )
```

It returns **true** if the button is pressed and **false** otherwise.

Here is a short program that demonstrates **ToggleButton**: 

```java
```
// Demonstrate a toggle button.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;

public class ToggleButtonDemo extends Application {

    ToggleButton tbOnOff;
    Label response;

    public static void main(String[] args) {

        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate a Toggle Button");

        // Use a FlowPane for the root node. In this case,
        // vertical and horizontal gaps of 10.
        FlowPane rootNode = new FlowPane(10, 10);

        // Center the controls in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 220, 120);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        // Create a label.
        response = new Label("Push the Button.");

        // Create the toggle button.
        tbOnOff = new ToggleButton("On/Off");
    }
}
// Handle action events for the toggle button.
tbOnOff.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        if(tbOnOff.isSelected()) response.setText("Button is on.");
        else response.setText("Button is off.");
    }
});

// Add the label and buttons to the scene graph.
rootNode.getChildren().addAll(tbOnOff, response);

// Show the stage and its scene.
myStage.show();

Sample output produced by the program is shown here, with the button pressed:

In the program, notice how the pressed/released state of the toggle button is determined by the following lines of code inside the button’s action event handler:

if(tbOnOff.isSelected()) response.setText("Button is on.");
else response.setText("Button is off.");

When the button is pressed, isSelected() returns true. When the button is released, isSelected() returns false.

One other point: It is possible to use two or more toggle buttons in a group. In this case, only one button can be in its pressed state at any one time. The process of creating and using a group of toggle buttons is similar to that required to use radio buttons. It is described in the following section.

RadioButton
Another type of button provided by JavaFX is the radio button. Radio buttons are a group of mutually exclusive buttons, in which only one button can be selected at any one time. They are supported by the RadioButton class, which extends both ButtonBase and ToggleButton. It also implements the Toggle interface. Thus, a radio button is a specialized form of a toggle button. You have almost certainly seen radio buttons in action because they are the primary control employed when the user must select only one option among several alternatives.

To create a radio button, we will use the following constructor:

RadioButton(String str)

Here, str is the label for the button. Like other buttons, when a RadioButton is used, an action event is generated.

For their mutually exclusive nature to be activated, radio buttons must be configured into a group. Only one of the buttons in the group can be selected at any time. For example, if a user presses a radio button that is in a group, any previously selected button in that group is automatically deselected. A button group is created by the ToggleGroup class, which is packaged in javafx.scene.control. ToggleGroup provides only a default constructor.

Radio buttons are added to the toggle group by calling the setToggleGroup( ) method, defined by ToggleButton, on the button. It is shown here:

final void setToggleGroup(ToggleGroup tg)

Here, tg is a reference to the toggle button group to which the button is added. After all radio buttons have been added to the same group, their mutually exclusive behavior will be enabled.

In general, when radio buttons are used in a group, one of the buttons is selected when the group is first displayed in the GUI. Here are two ways to do this.

First, you can call setSelected( ) on the button that you want to select. It is defined by ToggleButton (which is a superclass of RadioButton). It is shown here:

final void setSelected(boolean state)

If state is true, the button is selected. Otherwise, it is deselected. Although the button is selected, no action event is generated.

A second way to initially select a radio button is to call fire( ) on the button. It is shown here:

void fire( )
This method results in an action event being generated for the button if the button was previously not selected.

There are a number of different ways to use radio buttons. Perhaps the simplest is to simply respond to the action event that is generated when one is selected. The following program shows an example of this approach. It uses radio buttons to allow the user to select a type of transportation.

```java
// A simple demonstration of Radio Buttons.

// This program responds to the action events generated
// by a radio button selection. It also shows how to
// fire the button under program control.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;

public class RadioButtonDemo extends Application {

    Label response;

    public static void main(String[] args) {
```
// Start the JavaFX application by calling launch().
launch(args);
}

// Override the start() method.
public void start(Stage myStage) {

    // Give the stage a title.
    myStage.setTitle("Demonstrate Radio Buttons");

    // Use a FlowPane for the root node. In this case,
    // vertical and horizontal gaps of 10.
    FlowPane rootNode = new FlowPane(10, 10);

    // Center the controls in the scene.
    rootNode.setAlignment(Pos.CENTER);

    // Create a scene.
    Scene myScene = new Scene(rootNode, 220, 120);

    // Set the scene on the stage.
    myStage.setScene(myScene);

    // Create a label that will report the selection.
    response = new Label("");

    // Create the radio buttons.
    RadioButton rbTrain = new RadioButton("Train");
    RadioButton rbCar = new RadioButton("Car");
    RadioButton rbPlane = new RadioButton("Airplane");

    // Create a toggle group.
    ToggleGroup tg = new ToggleGroup();
// Add each button to a toggle group.
rbTrain.setToggleGroup(tg);
rbCar.setToggleGroup(tg);
rbPlane.setToggleGroup(tg);

// Handle action events for the radio buttons.
rbTrain.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        response.setText("Transport selected is train.");
    }
});

rbCar.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        response.setText("Transport selected is car.");
    }
});

rbPlane.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        response.setText("Transport selected is airplane.");
    }
});

// Fire the event for the first selection. This causes
// that radio button to be selected and an action event
// for that button to occur.
rbTrain.fire();

// Add the label and buttons to the scene graph.
rootNode.getChildren().addAll(rbTrain, rbCar, rbPlane, response);

// Show the stage and its scene.
myStage.show();
}

Sample output is shown here:
In the program, pay special attention to how the radio buttons and the toggle group are created. First, the buttons are created using this sequence:

```java
RadioButton rbTrain = new RadioButton("Train");
RadioButton rbCar = new RadioButton("Car");
RadioButton rbPlane = new RadioButton("Airplane");
```

Next, a `ToggleGroup` is constructed:

```java
ToggleGroup tg = new ToggleGroup();
```

Finally, each radio button is added to the toggle group:

```java
rbTrain.setToggleGroup(tg);
rbCar.setToggleGroup(tg);
rbPlane.setToggleGroup(tg);
```

As explained, radio buttons must be part of a toggle group in order for their mutually exclusive behavior to be activated.

After the event handlers for each radio button have been defined, the `rbTrain` button is selected by calling `fire()` on it. This causes that button to be selected and an action event to be generated for it. This causes the button to be initialized with the default selection.

**Handling Change Events in a Toggle Group**

Although there is nothing wrong, per se, with managing radio buttons by handling action events, as just shown, sometimes it is more appropriate (and easier) to listen to the entire toggle group for changes. When a change takes place, the event handler can easily determine which radio button has been selected and take action accordingly. To use this approach, you must register a `ChangeListener` on the toggle group. When a change event occurs, you can then determine which button was selected. To try this approach, remove the action event handlers and the call to `fire()` from the preceding program and substitute the following:
// Use a change listener to respond to a change of selection within
// the group of radio buttons.
tg.selectedToggleProperty().addListener(new ChangeListener<Toggle>() {
    public void changed(ObservableValue<? extends Toggle> changed,
        Toggle oldVal, Toggle newVal) {

        // Cast new to RadioButton.
        RadioButton rb = (RadioButton) newVal;

        // Display the selection.
        response.setText("Transport selected is " + rb.getText());
    }
});

// Select the first button. This will cause a change event
// on the toggle group.
rbTrain.setSelected(true);

You will also need to add this import statement:

import javafx.beans.value.*;

It supports the ChangeListener interface.

The output from this program is the same as before; each time a selection is made, the response label is updated. However, in this case, only one event handler is needed for the enter group, rather than three (one for each button). Let’s now look at this code more closely.

First, a change event listener is registered for the toggle group. To listen for change events, you must implement the ChangeListener interface. This is done by calling addListener() on the object returned by selectedToggleProperty(). The ChangeListener interface defines only one method, called changed(). It is shown here:

    void changed(ObservableValue<? extends T> changed, T oldVal, T newVal)

In this case, changed is the instance of ObservableValue<T>, which encapsulates an object that can be watched for changes. The oldVal and newVal parameters pass the previous value and the new value, respectively. Thus, in this case, newVal holds a reference to the radio button that has just been selected.

In this example, the setSelected() method, rather than fire(), is called to set the initial selection. Because setting the initial selection causes a change to the toggle group, it results in a change event being generated when the program first begins.
You can also use `fire()`, but `setSelected()` was used to demonstrate that any change to the toggle group generates a change event.

An Alternative Way to Handle Radio Buttons

Although handling events generated by radio buttons is often useful, sometimes it is more appropriate to ignore those events and simply obtain the currently selected button when that information is needed. This approach is demonstrated by the following program. It adds a button called Confirm Transport Selection. When this button is pressed, the currently selected radio button is obtained and then the selected transport is displayed in a label. When you try the program, notice that changing the selected radio button does not cause the confirmed transport to change until you press the Confirm Transport Selection button.
// This radio button example demonstrates how the
// currently selected button in a group can be obtained
// under program control, when it is needed, rather
// than responding to action or change events.
//
// In this example, no events related to the radio
// buttons are handled. Instead, the current selection
// is simply obtained when the Confirm Transport Selection push
// button is pressed.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;

public classRadioButtonDemo2 extends Application {

    Label response;
    ToggleGroup tg;

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate Radio Buttons");

        // Use a FlowPane for the root node. In this case,
        // vertical and horizontal gaps of 10.
        FlowPane rootNode = new FlowPane(10, 10);

        // Center the controls in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 200, 140);

        // Set the scene on the stage.
        myStage.setScene(myScene);
// Create two labels.
Label choose = new Label("Select a Transport Type");
response = new Label("No transport confirmed");

// Create push button used to confirm the selection.
Button btnConfirm = new Button("Confirm Transport Selection");

// Create the radio buttons.
RadioButton rbTrain = new RadioButton("Train");
RadioButton rbCar = new RadioButton("Car");
RadioButton rbPlane = new RadioButton("Airplane");

// Create a toggle group.
tg = new ToggleGroup();

// Add each button to a toggle group.
rbTrain.setToggleGroup(tg);
rbCar.setToggleGroup(tg);
rbPlane.setToggleGroup(tg);

// Initially select one of the radio buttons.
rbTrain.setSelected(true);

// Handle action events for the confirm button.
btnConfirm.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        // Get the radio button that is currently selected.
        RadioButton rb = (RadioButton) tg.getSelectedToggle();

        // Display the selection.
        response.setText(rb.getText() + " is confirmed.");
    }
});

// Use a separator to better organize the layout.
Separator separator = new Separator();
separator.setPrefWidth(180);

// Add the label and buttons to the scene graph.
rootNode.getChildren().addAll(choose, rbTrain, rbCar, rbPlane,
                                separator, btnConfirm, response);

// Show the stage and its scene.
myStage.show();
The output from the program is shown here:

Most of the program is easy to understand, but two key points are of special interest. First, inside the action event handler for the **btnConfirm** button, notice that the selected radio button is obtained by the following line:

```java
RadioButton rb = (RadioButton) tg.getSelectedToggle();
```

Here, the `getSelectedToggle()` method (defined by `ToggleGroup`) obtains the current selection for the toggle group (which, in this case, is a group of radio buttons). It is shown here:

```java
final Toggle getSelectedToggle()
```

It returns a reference to the `Toggle` that is selected. In this case, the return value is cast to `RadioButton` because this is the type of button in the group.

The second thing to notice is the use of a visual separator, which is created by this sequence:

```java
Separator separator = new Separator();
separator.setPrefWidth(180);
```

The `Separator` class creates a line, which can be either vertical or horizontal. By default, it creates a horizontal line. (A second constructor lets you choose a vertical separator.) `Separator` helps visually organize the layout of controls. It is packaged in `javafx.scene.control`. Next, the width of the separator line is set by calling `setPrefWidth()`, passing in the width.

**CheckBox**

The `CheckBox` class encapsulates the functionality of a check box. Its immediate superclass is `ButtonBase`. Although you are no doubt familiar with check boxes
because they are widely used controls, the JavaFX check box is a bit more sophisticated than you may at first think. This is because **CheckBox** supports three states. The first two are checked or unchecked, as you would expect, and this is the default behavior. The third state is *indeterminate* (also called *undefined*). It is typically used to indicate that the state of the check box has not been set or that it is not relevant to a specific situation. If you need the indeterminate state, you will need to explicitly enable it.

**CheckBox** defines two constructors. The first is the default constructor. The second lets you specify a string that identifies the box. It is shown here:

```
CheckBox(String str)
```

It creates a check box that has the text specified by *str* as a label. As with other buttons, a **CheckBox** generates an action event when it is selected.

Here is a program that demonstrates check boxes. It displays check boxes that let the user select various deployment options, which are Web, Desktop, and Mobile. Each time a check box state changes, an action event is generated and handled by displaying the new state (selected or cleared) and by displaying a list of all selected boxes.

```
// Demonstrate Check Boxes.

import javafx.application.*;
import javafx.scene.*;
```
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;

public class CheckboxDemo extends Application {

    CheckBox cbWeb;
    CheckBox cbDesktop;
    CheckBox cbMobile;

    Label response;
    Label allTargets;

    String targets = "";

    public static void main(String[] args) {

        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

    }
// Give the stage a title.
myStage.setTitle("Demonstrate Checkboxes");

// Use a FlowPane for the root node. In this case, // vertical and horizontal gaps of 10.
FlowPane rootNode = new FlowPane(10, 10);

// Center the controls in the scene.
rootNode.setAlignment(Pos.CENTER);

// Create a scene.
Scene myScene = new Scene(rootNode, 230, 140);

// Set the scene on the stage.
myStage.setScene(myScene);

Label heading = new Label("Select Deployment Options");

// Create a label that will report the state of the // selected check box.
response = new Label("No Deployment Selected");

// Create a label that will report all targets selected.
allTargets = new Label("Target List: &lt;none&gt;");

// Create the check boxes.
cbWeb = new CheckBox("Web");
cbDesktop = new CheckBox("Desktop");
cbMobile = new CheckBox("Mobile");

// Handle action events for the check boxes.
cbWeb.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        if (cbWeb.isSelected())
            response.setText("Web deployment selected.");
        else
            response.setText("Web deployment cleared.");

        showAll();
    }
});

cbDesktop.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        if (cbDesktop.isSelected())
            response.setText("Desktop deployment selected.");
        else
            response.setText("Desktop deployment cleared.");

        showAll();
    }
});
cbMobile.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        if (cbMobile.isSelected())
            response.setText("Mobile deployment selected.");
        else
            response.setText("Mobile deployment cleared.");

        showAll();
    }
});

// Use a separator to better organize the layout.
Separator separator = new Separator();
separator.setPrefWidth(200);

// Add controls to the scene graph.
rootNode.getChildren().addAll(heading, separator, cbWeb, cbDesktop,
                               cbMobile, response, allTargets);

// Show the stage and its scene.
myStage.show();

// Update and show the targets list.
void showAll() {
    targets = "";
    if (cbWeb.isSelected()) targets = "Web ";
    if (cbDesktop.isSelected()) targets += "Desktop ";
    if (cbMobile.isSelected()) targets += "Mobile";

    if (targets.equals("")) targets = "<none>";

    allTargets.setText("Target List: " + targets);
}

Sample output is shown here:
The operation of this program is straightforward. Each time a check box is changed, an action command is generated. To determine if the box is checked or unchecked, the `isSelected()` method is called.

As mentioned, by default, `CheckBox` implements two states: checked and unchecked. If you want to add the indeterminate state, it must be explicitly enabled. To do this, call `setAllowIndeterminate()`, shown here:

```java
final void setAllowIndeterminate(boolean enable)
```

In this case, if `enable` is `true`, the indeterminate state is enabled. Otherwise, it is disabled. When the indeterminate state is enabled, the user can select between checked, unchecked, and indeterminate.

You can determine if a check box is in the indeterminate state by calling `isIndeterminate()`, shown here:

```java
final boolean isIndeterminate()
```

It returns `true` if the checkbox state is indeterminate and `false` otherwise.

You can see the effect of a three-state check box by modifying the preceding program. First, enable the indeterminate state on the check boxes by calling `setAllowIndeterminate()` on each check box, as shown here:

```java
cbWeb.setAllowIndeterminate(true);
cbDesktop.setAllowIndeterminate(true);
cbMobile.setAllowIndeterminate(true);
```

Next, handle the indeterminate state inside the action event handlers. For example, here is the modified handler for `cbWeb`:
cbWeb.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        if (cbWeb.isSelected())
            response.setText("Web deployment selected.");
        else if (cbWeb.isIndeterminate())
            response.setText("Web deployment indeterminate.");
        else
            response.setText("Web deployment cleared.");

        showAll();
    }
});

Now, all three states are tested. Update the other two handlers in the same way. After making these changes, the indeterminate state can be selected, as this sample output shows:

Here, the Web check box is indeterminate.

**ListView**

Another commonly used control is the list view, which in JavaFX is encapsulated by ListView. List views are controls that display a list of entries from which you can select one or more. Because of their ability to make efficient use of limited screen space, list views are popular alternatives to other types of selection controls.

ListView is a generic class that is declared like this:

```java
class ListView<T>
```

Here, **T** specifies the type of entries stored in the list view. Often, these are entries of type String, but other types are also allowed.

ListView defines two constructors. The first is the default constructor, which
creates an empty `ListView`. The second lets you specify the list of entries in the list. It is shown here:

```
ListView/ObservableList<T> list
```

Here, `list` specifies a list of the items that will be displayed. It is an object of type `ObservableList`, which defines a list of observable objects. It inherits `java.util.List`. Thus, it supports the standard collection methods. `ObservableList` is packaged in `javafx.collections`.

Probably the easiest way to create an `ObservableList` for use in a `ListView` is to use the factory method `observableArrayList( )`, which is a static method defined by the `FXCollections` class (which is also packaged in `javafx.collections`). The version we will use is shown here:

```
static <E> ObservableList/E> observableArrayList( E … elements)
```

In this case, `E` specifies the type of elements, which are passed via `elements`.

By default, a `ListView` allows only one item in the list to be selected at any one time. However, you can allow multiple selections by changing the selection mode. For now, we will use the default, single-selection model.

Although `ListView` provides a default size, sometimes you will want to set the preferred height and/or width to best match your needs. One way to do this is to call the `setPrefHeight( )` and `setPrefWidth( )` methods, shown here:

```
final void setPrefHeight(double height)
final void setPrefWidth(double width)
```

Alternatively, you can use a single call to set both dimensions at the same time by use of `setPrefSize( )`, shown here:

```
void setPrefSize(double width, double height)
```

There are two basic ways in which you can use a `ListView`. First, you can ignore events generated by the list and simply obtain the selection in the list when your program needs it. Second, you can monitor the list for changes by registering a change listener. This lets you respond each time the user changes a selection in the list. This is the approach used here.

To listen for change events, you must first obtain the selection model used by the `ListView`. This is done by calling `getSelectionModel( )` on the list. It is shown here:
final MultipleSelectionModel<T> getSelectionModel()

It returns a reference to the model. *MultipleSelectionModel* is a class that defines the model used for multiple selections, and it inherits *SelectionModel*. However, multiple selections are allowed in a *ListView* only if multiple-selection mode is turned on.

Using the model returned by *getSelectionModel()* , you will obtain a reference to the selected item property that defines what takes place when an element in the list is selected. This is done by calling *selectedItemProperty()* , shown next:

```java
final ReadOnlyObjectProperty<T> selectedItemProperty()
```

You will add the change listener to this property.

The following example puts the preceding discussion into action. It creates a list view that displays various types of transportation, allowing the user to select one. When one is chosen, the selection is displayed.

```java
// Demonstrate a list view.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.geometry.*;
import javafx.beans.value.*;
import javafx.collections.*;

public class ListViewDemo extends Application {

    Label response;
```
public static void main(String[] args) {

    // Start the JavaFX application by calling launch().
    launch(args);
}

// Override the start() method.
public void start(Stage myStage) {

    // Give the stage a title.
    myStage.setTitle("ListView Demo");

    // Use a FlowPane for the root node. In this case,
    // vertical and horizontal gaps of 10.
    FlowPane rootNode = new FlowPane(10, 10);

    // Center the controls in the scene.
    rootNode.setAlignment(Pos.CENTER);

    // Create a scene.
    Scene myScene = new Scene(rootNode, 200, 120);

    // Set the scene on the stage.
    myStage.setScene(myScene);

    // Create a label.
    response = new Label("Select Transport Type");
// Create an ObservableList of entries for the list view.
ObservableList<String> transportTypes =
   FXCollections.observableArrayList( "Train", "Car", "Airplane" );

// Create the list view.
ListView<String> lvTransport = new ListView<String>(transportTypes);

// Set the preferred height and width.
lvTransport.setPrefSize(80, 80);

// Get the list view selection model.
MultipleSelectionModel<String> lvSelModel =
   lvTransport.getSelectionModel();

// Use a change listener to respond to a change of selection within
// a list view.
 lvSelModel.selectedItemProperty().addListener(
   new ChangeListener<String>() {
      public void changed(ObservableValue<? extends String> changed,
                          String oldVal, String newVal) {

      // Display the selection.
         response.setText("Transport selected is " + newVal);
      }
   });

   // Add the label and list view to the scene graph.
   rootNode.getChildren().addAll(lvTransport, response);

   // Show the stage and its scene.
   myStage.show();
}

Sample output is shown here:

![Image of ListView with options: Train, Car, Airplane, and selected option: Airplane]
In the program, pay special attention to how the **ListView** is constructed. First, an **ObservableList** is created by this line:

```java
ObservableList<String> transportTypes = FXCollections.observableArrayList("Train", "Car", "Airplane");
```

It uses the `observableArrayList()` method to create a list of strings. Then, the **ObservableList** is used to initialize a **ListView**, as shown here:

```java
ListView<String> lvTransport = new ListView<String>(transportTypes);
```

The program then sets the preferred width and height of the control.

Now, notice how the selection model is obtained for `lvTransport`:

```java
MultipleSelectionModel<String> lvSelModel = lvTransport.getSelectionModel();
```

As explained, **ListView** uses **MultipleSelectionModel**, even when only a single selection is allowed. The `selectedItemProperty()` method is then called on the model and a change listener is registered to the returned item.

**ListView Scroll Bars**

One very useful feature of **ListView** is that when the number of items in the list exceeds the number that can be displayed within its dimensions, scroll bars are automatically added. For example, if you change the declaration of `transportTypes` so that it includes "Bicycle" and "Walking", as shown here:

```java
ObservableList<String> transportTypes = FXCollections.observableArrayList("Train", "Car", "Airplane", "Bicycle", "Walking");
```

the `lvTransport` control now looks like the one shown here:

![ListView Example](image-url)
Enabling Multiple Selections

If you want to allow more than one item to be selected, you must explicitly request it. To do so, you must set the selection mode to `SelectionMode.MULTIPLE` by calling `setSelectionMode()` on the `ListView` model. It is shown here:

```java
final void setSelectionMode(SelectionMode mode)
```

In this case, `mode` must be either `SelectionMode.MULTIPLE` or `SelectionMode.SINGLE`.

When multiple-selection mode is enabled, you can obtain the list of the selections two ways: as a list of selected indices or as a list of selected items. We will use a list of selected items, but the procedure is similar when using a list of the indices of the selected items. (Note, indexing of items in a `ListView` begins at zero.)

To get a list of the selected items, call `getSelectedItems()` on the selection model. It is shown here:

```java
ObservableList<T> getSelectedItems()
```

It returns an `ObservableList` of the items. Because `ObservableList` extends `java.util.List`, you can access the items in the list just as you would any other `List` collection.

To experiment with multiple selections, you can modify the preceding program as follows. First, add this line:

```java
lvTransport.getSelectionModel().setSelectionMode(SelectionMode.MULTIPLE);
```

It enables multiple-selection mode for `lvTransport`. Next, replace the change event handler with the one shown here:
After making these changes, the program will display all selected forms of transports, as the following output shows:

![ComboBox example](image)

**ComboBox**

A control related to the list view is the combo box, which is implemented in JavaFX by the **ComboBox** class. A combo box displays one selection, but it will also display a drop-down list that allows the user to select a different item. You can also allow the user to edit a selection. **ComboBox** inherits **ComboBoxBase**, which provides much of its functionality. Unlike the **ListView**, which can allow multiple selections, **ComboBox** is designed for single-selection.

**ComboBox** is a generic class that is declared like this:

```java
class ComboBox<T>
```
Here, \( T \) specifies the type of entries. Often, these are entries of type \texttt{String}, but other types are also allowed.

\textbf{ComboBox} defines two constructors. The first is the default constructor, which creates an empty \texttt{ComboBox}. The second lets you specify the list of entries. It is shown here:

\begin{verbatim}
ComboBox(ObservableList\langle T\rangle list)
\end{verbatim}

In this case, \textit{list} specifies a list of the items that will be displayed. It is an object of type \texttt{ObservableList}, which defines a list of observable objects. As explained in the previous section, \texttt{ObservableList} inherits \texttt{java.util.List}. As also previously explained, an easy way to create an \texttt{ObservableList} is to use the factory method \texttt{observableArrayList()}, which is a static method defined by the \texttt{FXCollections} class.

A \texttt{ComboBox} generates an action event when its selection changes. It will also generate a change event. Alternatively, it is also possible to ignore events and simply obtain the current selection when needed.

You can obtain the current selection by calling \texttt{getValue()}, shown here:

\begin{verbatim}
final T getValue()
\end{verbatim}

If the value of a combo box has not yet been set (by the user or under program control), then \texttt{getValue()} will return \texttt{null}. To set the value of a \texttt{ComboBox} under program control, call \texttt{setValue()}:

\begin{verbatim}
final void setValue(T newVal)
\end{verbatim}

Here, \textit{newVal} becomes the new value.

The following program demonstrates a combo box by reworking the previous list view example. It handles the action event generated by the combo box.
// Demonstrate a combo box.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.geometry.*;
import javafx.collections.*;
import javafx.event.*;

public class ComboBoxDemo extends Application {

    ComboBox<String> cbTransport;
    Label response;

    public static void main(String[] args) {

        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("ComboBox Demo");

        // Use a FlowPane for the root node. In this case,
        // vertical and horizontal gaps of 10.
        FlowPane rootNode = new FlowPane(10, 10);

        // Center the controls in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 280, 120);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        // Create a label.
        response = new Label();
// Create an ObservableList of entries for the combo box.
ObservableList<String> transportTypes =
    FXCollections.observableArrayList("Train", "Car", "Airplane");

// Create a combo box.
comboBox = new ComboBox<String>(transportTypes);

// Set the default value.
comboBox.setValue("Train");

// Set the response label to indicate the default selection.
response.setText("Selected Transport is " + comboBox.getValue());

// Listen for action events on the combo box.
comboBox.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        response.setText("Selected Transport is " + comboBox.getValue());
    }
});

// Add the label and combo box to the scene graph.
rootNode.getChildren().addAll(comboBox, response);

// Show the stage and its scene.
myStage.show();
}

Sample output is shown here:
As mentioned, **ComboBox** can be configured to allow the user to edit a selection. Assuming that it contains only entries of type **String**, it is easy to enable editing capabilities. Simply call **setEditable()**, shown here:

```java
final void setEditable(boolean enable)
```

If `enable` is `true`, editing is enabled. Otherwise, it is disabled. To see the effects of editing, add this line to the preceding program:

```java
cbTransport.setEditable(true);
```

After making this addition, you will be able to edit the selection.

**ComboBox** supports many additional features and functionality beyond those mentioned here. You might find it interesting to explore further. Also, an alternative to a combo box in some cases is the **ChoiceBox** control. You will find it easy to use because it is has similarities to both **ListView** and **ComboBox**.

**TextField**

Although the controls discussed earlier are quite useful and are frequently found in a user interface, they all implement a means of selecting a predetermined option or action. However, sometimes you will want the user to enter a string of his or her own choosing. To accommodate this type of input, JavaFX includes several text-based controls. The one we will look at is **TextField**. It allows one line of text to be entered. Thus, it is useful for obtaining names, ID strings, addresses, and the like. Like all text controls, **TextField** inherits **TextInputControl**, which defines much of its functionality.

**TextField** defines two constructors. The first is the default constructor, which creates an empty text field that has the default size. The second lets you specify the initial contents of the field. Here, we will use the default constructor.

Although the default size is sometimes adequate, often you will want to specify its size. This is done by calling **setPrefColumnCount()**, shown here:

```java
final void setPrefColumnCount(int columns)
```

The `columns` value is used by **TextField** to determine its size.

You can set the text in a text field by calling **setText()**. You can obtain the current text by calling **getText()**. In addition to these fundamental operations, **TextField** supports several other capabilities that you might want to explore, such as cut, paste, and append. You can also select a portion of the text under program
control.

One especially useful TextField option is the ability to set a prompting message inside the text field when the user attempts to use a blank field. To do this, call setPromptText(), shown here:

```java
final void setPromptText(String str)
```

In this case, str is the string displayed in the text field when no text has been entered. It is displayed using low-intensity (such as a gray tone).

When the user presses enter while inside a TextField, an action event is generated. Although handling this event is often helpful, in some cases, your program will simply obtain the text when it is needed, rather than handling action events. Both approaches are demonstrated by the following program. It creates a text field that requests a search string. When the user presses enter while the text field has input focus, or presses the Get Search String button, the string is obtained and displayed. Notice that a prompting message is also included.
// Demonstrate a text field.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;

public class TextFieldDemo extends Application {

    TextField tf;
    Label response;

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate a TextField");

        // Use a FlowPane for the root node. In this case,
        // vertical and horizontal gaps of 10.
        FlowPane rootNode = new FlowPane(10, 10);

        // Center the controls in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 230, 140);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        // Create a label that will report the contents of the
        // text field.
        response = new Label("Search String: ");

        // Create a button that gets the text.
        Button btnGetText = new Button("Get Search String");

        // Create a text field.
        tf = new TextField();
// Set the prompt.
tf.setPromptText("Enter Search String");

// Set preferred column count.
tf.setPrefColumnCount(15);

// Handle action events for the text field. Action
// events are generated when ENTER is pressed while
// the text field has input focus. In this case, the
// text in the field is obtained and displayed.
tf.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        response.setText("Search String: " + tf.getText());
    }
});

// Get text from the text field when the button is pressed
// and display it.
btnGetText.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        response.setText("Search String: " + tf.getText());
    }
});

// Use a separator to better organize the layout.
Separator separator = new Separator();
separator.setPrefWidth(180);

// Add controls to the scene graph.
rootNode.getChildren().addAll(tf, btnGetText, separator, response);

// Show the stage and its scene.
myStage.show();

Sample output is shown here:
Other text controls that you will want to examine include **TextArea**, which supports multiline text, and **PasswordField**, which can be used to input passwords. You might also find **TextInputDialog** and **HTMLEditor** helpful.

**ScrollPane**

Sometimes, the contents of a control will exceed the amount of screen space that you want to give to it. Here are two examples: A large image may not fit within reasonable boundaries, or you might want to display text that is longer than will fit within a small window. Whatever the reason, JavaFX makes it easy to provide scrolling capabilities to any node in a scene graph. This is accomplished by wrapping the node in a **ScrollPane**. When a **ScrollPane** is used, scroll bars are automatically implemented that scroll the contents of the wrapped node. No further action is required on your part. Because of the versatility of **ScrollPane**, you will seldom need to use individual scroll bar controls.

**ScrollPane** defines two constructors. The first is the default constructor. The second lets you specify a node that you want to scroll. It is shown here:

```java
ScrollPane(Node content)
```

In this case, `content` specifies the information to be scrolled. When using the default constructor, you will add the node to be scrolled by calling `setContent()`. It is shown here:

```java
final void setContent(Node content)
```

After you have set the content, add the scroll pane to the scene graph. When displayed, the content can be scrolled.

**NOTE** You can also use `setContent()` to change the content being scrolled by the scroll pane. Thus, what is being scrolled can be changed during the execution of
your program.

Although a default size is provided, as a general rule, you will want to set the dimensions of the viewport. The viewport is the viewable area of a scroll pane. It is the area in which the content being scrolled is displayed. In other words, the viewport displays the visible portion of the content. The scroll bars scroll the content through the viewport. Thus, by moving a scroll bar, you change what part of the content is visible.

You can set the viewport dimensions by using these two methods:

```java
final void setPrefViewportHeight(double height)
final void setPrefViewportWidth(double width)
```

In its default behavior, a ScrollPane will dynamically add or remove a scroll bar as needed. For example, if the component is taller than the viewport, a vertical scroll bar is added. If the component will completely fit within the viewport, the scroll bars are removed.

One nice feature of ScrollPane is its ability to pan the contents by dragging the mouse. By default, this feature is off. To turn it on, use setPannable(), shown here:

```java
final void setPannable(boolean enable)
```

If enable is true, then panning is allowed. Otherwise, it is disabled.

You can set the position of the scroll bars under program control using setHvalue() and setVvalue(), shown here:

```java
final void setHvalue(double newHval)
final void setVvalue(double newVval)
```

The new horizontal position is specified by newHval, and the new vertical position is specified by newVval. By default, scroll bar positions start at zero.

ScrollPane supports various other options. For example, it is possible to set the minimum and maximum scroll bar positions. You can also specify when and if the scroll bars are shown by setting a scroll bar policy. The current position of the scroll bars can be obtained by calling getHvalue() and getVvalue().

The following program demonstrates ScrollPane by using one to scroll the contents of a multiline label. Notice that it also enables panning.
// Demonstrate a scroll pane.
// This program scrolls the contents of a multiline
// label, but any node can be scrolled.

import javafx.application.*/;
import javafx.scene.*/;
import javafx.stage.*/;
import javafx.scene.layout.*/;
import javafx.scene.control.*/;
import javafx.event.*/;
import javafx.geometry.*/;

public class ScrollPaneDemo extends Application {

    ScrollPane scrlPane;

    public static void main(String[] args) {

        // Start the JavaFX application by calling launch() .
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate a ScrollPane");

        // Use a FlowPane for the root node.
        FlowPane rootNode = new FlowPane(10, 10);

        // Center the controls in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 200, 200);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        // Create a label that will be scrolled.
        Label scrlLabel = new Label("A ScrollPane streamlines the process of\n" +
Sample output is shown here:
TreeView

One of JavaFX’s most powerful controls is the **TreeView**. It presents a hierarchical view of data in a tree-like format. In this context, the term *hierarchical* means some items are subordinate to others. For example, a tree is commonly used to display the contents of a file system. In this case, the individual files are subordinate to the directory that contains them. In a **TreeView**, branches can be expanded or collapsed on demand by the user. This allows hierarchical data to be presented in a compact, yet expandable form. Although **TreeView** supports many customization options, you will often find that the default tree style and capabilities are suitable. Therefore, even though trees support a sophisticated structure, they are still quite easy to work with.

**TreeView** implements a conceptually simple, tree-based data structure. A tree begins with a single *root node* that indicates the start of the tree. Under the root are one or more *child nodes*. There are two types of child nodes: *leaf nodes* (also called *terminal nodes*), which have no children, and *branch nodes*, which form the root nodes of *subtrees*. A subtree is simply a tree that is part of a larger tree. The sequence of nodes that leads from the root to a specific node is called a *path*.

One very useful feature of **TreeView** is that it automatically provides scroll bars when the size of the tree exceeds the dimensions of the view. Although a fully collapsed tree might be quite small, its expanded form may be quite large. By automatically adding scroll bars as needed, **TreeView** lets you use a smaller space than would ordinarily be possible.

**TreeView** is a generic class that is defined like this:

```java
class TreeView<T>
```

Here, \( T \) specifies the type of value held by an item in the tree. Often, this will be of
type **String**. **TreeView** defines two constructors. This is the one we will use:

```
TreeView(TreeItem<T> rootNode)
```

Here, `rootNode` specifies the root of the tree. Because all nodes descend from the root, it is the only one that needs to be passed to **TreeView**.

The items that form the tree are objects of type **TreeItem**. At the outset, it is important to state that **TreeItem** does not inherit **Node**. Thus, **TreeItems** are not general-purpose objects. They can be used in a **TreeView**, but not as stand-alone controls. **TreeItem** is a generic class, as shown here:

```
class TreeItem<T>
```

Here, `T` specifies the type of value held by the **TreeItem**.

Before you can use a **TreeView**, you must construct the tree that it will display. To do this, you must first create the root. Next, add other nodes to that root. You do this by calling either `add()` or `addAll()` on the list returned by `getChildren()`. These other nodes can be leaf nodes or subtrees. After the tree has been constructed, you create the **TreeView** by passing the root node to its constructor.

You can handle selection events in the **TreeView** in a way similar to the way that you handle them in a **ListView**, through the use of a change listener. To do so, first, obtain the selection model by calling `getSelectionModel()`. Then, call `selectedItemProperty()` to obtain the property for the selected item. On that return value, call `addListener()` to add a change listener. Each time a selection is made, a reference to the new selection will be passed to the `changed()` handler as the new value. (See **ListView** for more details on handling change events.)

You can obtain the value of a **TreeItem** by calling `getValue()`. You can also follow the tree path of an item in either the forward or backward direction. To obtain the parent, call `getParent()`. To obtain the children, call `getChildren()`.

The following example shows how to build and use a **TreeView**. The tree presents a hierarchy of food. The type of items stored in the tree are strings. The root is labeled Food. Under it are three direct descendent nodes: Fruit, Vegetables, and Nuts. Under Fruit are three child nodes: Apples, Pears, and Oranges. Under Apples are three leaf nodes: Fuji, Winesap, and Jonathan. Each time a selection is made, the name of the item is displayed. Also, the path from the root to the item is shown. This is done by the repeated use of `getParent()`.
// Demonstrate a TreeView

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.beans.value.*;
import javafx.geometry.*;

public class TreeViewDemo extends Application {

    Label response;

    public static void main(String[] args) {

        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate a TreeView");

        // Use a FlowPane for the root node. In this case,
        // vertical and horizontal gaps of 10.
        FlowPane rootNode = new FlowPane(10, 10);

        // Center the controls in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 310, 460);

        // Set the scene on the stage.
        myStage.setScene(myScene);
    }
}
// Create a label that will report the state of the
// selected tree item.
response = new Label("No Selection");

// Create tree items, starting with the root.
TreeItem<String> tiRoot = new TreeItem<String>("Food");

// Now add subtrees, beginning with fruit.
TreeItem<String> tiFruit = new TreeItem<String>("Fruit");

// Construct the Apple subtree.
TreeItem<String> tiApples = new TreeItem<String>("Apples");

// Add child nodes to the Apple node.
tiApples.getChildren().add(new TreeItem<String>("Fuji"));
tiApples.getChildren().add(new TreeItem<String>("Winesap"));
tiApples.getChildren().add(new TreeItem<String>("Jonathan"));

// Add varieties to the fruit node.
tiFruit.getChildren().add(tiApples);
tiFruit.getChildren().add(new TreeItem<String>("Pears"));
tiFruit.getChildren().add(new TreeItem<String>("Oranges"));

// Finally, add the fruit node to the root.
tiRoot.getChildren().add(tiFruit);
// Now, add vegetables subtree, using the same general process.
TreeItem<String> tiVegetables = new TreeItem<String>("Vegetables");
tiVegetables.getChildren().add(new TreeItem<String>("Corn");
tiVegetables.getChildren().add(new TreeItem<String>("Peas");
tiVegetables.getChildren().add(new TreeItem<String>("Broccoli");
tiVegetables.getChildren().add(new TreeItem<String>("Beans");
tiRoot.getChildren().add(tiVegetables);

// Likewise, add nuts subtree.
TreeItem<String> tiNuts = new TreeItem<String>("Nuts");
tiNuts.getChildren().add(new TreeItem<String>("Walnuts");
tiNuts.getChildren().add(new TreeItem<String>("Peanuts");
tiNuts.getChildren().add(new TreeItem<String>("Pecans");
tiRoot.getChildren().add(tiNuts);

// Create tree view using the tree just created.
TreeView<String> tvFood = new TreeView<String>(tiRoot);

// Get the tree view selection model.
MultipleSelectionModel<TreeItem<String>> tvSelModel =
    tvFood.getSelectionModel();

// Use a change listener to respond to a selection within
// a tree view
tvSelModel.selectedItemProperty().addListener(
    new ChangeListener<TreeItem<String>>() {
        public void changed(
            ObservableValue<? extends TreeItem<String>> changed,
            TreeItem<String> oldVal, TreeItem<String> newVal) {
            
        }
    });
// Display the selection and its complete path from the root.
if(newVal != null) {

    // Construct the entire path to the selected item.
    String path = newVal.getValue();
    TreeItem<String> tmp = newVal.getParent();
    while(tmp != null) {
        path = tmp.getValue() + " -> " + path;
        tmp = tmp.getParent();
    }

    // Display the selection and the entire path.
    response.setText("Selection is " + newVal.getValue() + 
            "\nComplete path is " + path);
}
}

// Add controls to the scene graph.
rootNode.getChildren().addAll(tvFood, response);

// Show the stage and its scene.
myStage.show();
There are two things to pay special attention to in this program. First, notice how the tree is constructed. First, the root node is created by this statement:

```java
TreeItem<String> tiRoot = new TreeItem<String>("Food");
```

Next, the nodes under the root are constructed. These nodes consist of the root nodes of subtrees: one for fruit, one for vegetables, and one for nuts. Next, the leaves are added to these subtrees. However, one of these, the fruit subtree, consists of another subtree that contains varieties of apples. The point here is that each branch in a tree leads either to a leaf or to the root of a subtree. After all of the nodes have been constructed, the root nodes of each subtree are added to the root node of the tree. This is done by calling `add()` on the root node. For example, this is how the Nuts subtree is added to `tiRoot`:

```java
tiRoot.getChildren().add(tiNuts);
```

The process is the same for adding any child node to its parent node.
The second thing to notice in the program is the way the path from the root to the selected node is constructed within the change event handler. It is shown here:

```java
String path = newVal.getValue();
TreeItem<String> tmp = newVal.getParent();
while(tmp != null) {
    path = tmp.getValue() + " -" + path;
    tmp = tmp.getParent();
}
```

The code works like this: First, the value of the newly selected node is obtained. In this example, the value will be a string, which is the node’s name. This string is assigned to the `path` string. Then, a temporary variable of type `TreeItem<String>` is created and initialized to refer to the parent of the newly selected node. If the newly selected node does not have a parent, then `tmp` will be null. Otherwise, the loop is entered, within which each parent’s value (which is its name in this case) is added to `path`. This process continues until the root node of the tree (which has no parent) is found.

Although the preceding shows the basic mechanism required to handle a `TreeView`, it is important to point out that several customizations and options are supported. `TreeView` is a powerful control that you will want to examine fully on your own.

**Introducing Effects and Transforms**

A principal advantage of JavaFX is its ability to alter the precise look of a control (or any node in the scene graph) through the application of an `effect` and/or a `transform`. Both effects and transforms help give your GUI the sophisticated, modern look that users have come to expect. Although it is beyond the scope of this book to examine each effect and transform supported by JavaFX, the following introduction will give you an idea of the benefits they provide.

**Effects**

Effects are supported by the abstract `Effect` class and its concrete subclasses, which are packaged in `javafx.scene.effect`. Using these effects, you can customize the way a node in a scene graph looks. Several built-in effects are provided. Here is a sampling:
These, and the other effects, are easy to use and are available for use by any Node, including controls. Of course, depending on the control, some effects will be more appropriate than others.

To set an effect on a node, call `setEffect()`, which is defined by Node. It is shown here:

```java
final void setEffect(Effect effect)
```

Here, `effect` is the effect that will be applied. To specify no effect, pass `null`. Thus, to add an effect to a node, first create an instance of that effect and then pass it to `setEffect()`. Once this has been done, the effect will be used whenever the node is rendered (as long as the effect is supported by the environment). To demonstrate the power of effects, we will use two of them: Glow and InnerShadow. However, the process of adding an effect is essentially the same no matter what effect you choose.

Glow produces an effect that gives a node a glowing appearance. The amount of glow is under your control. To use a glow effect, you must first create a Glow instance. This is the constructor that we will use:

```java
Glow(double glowLevel)
```

Here, `glowLevel` specifies the amount of glowing, which must be a value between 0.0 and 1.0.

After a Glow instance has been created, the glow level can be changed by using `setLevel()`, shown here:

```java
final void setLevel(double glowLevel)
```

As before, `glowLevel` specifies the glow level, which must be between 0.0 and 1.0.

InnerShadow produces an effect that simulates a shadow on the inside of the node. It supports various constructors. This is the one we will use:

```java
InnerShadow
```
InnerShadow(double \textit{radius}, Color \textit{shadowColor})

Here, \textit{radius} specifies the radius of the shadow inside the node. In essence, the radius describes the size of the shadow. The color of the shadow is specified by \textit{shadowColor}. Here, the type \textbf{Color} is the JavaFX type \texttt{javafx.scene.paint.Color}. It defines a large number of constants, such as \texttt{Color.GREEN}, \texttt{Color.RED}, and \texttt{Color.BLUE}, which makes it easy to use.

**Transforms**

Transforms are supported by the abstract \textbf{Transform} class, which is packaged in \texttt{javafx.scene.transform}. Four of its subclasses are \textbf{Rotate}, \textbf{Scale}, \textbf{Shear}, and \textbf{Translate}. Each does what its name suggests. (Another subclass is \textbf{Affine}, but typically you will use one or more of the preceding transform classes.) It is possible to perform more than one transform on a node. For example, you could rotate it and scale it. Transforms are supported by the \textbf{Node} class as described next.

One way to add a transform to a node is to add it to the list of transforms maintained by the node. This list is obtained by calling \texttt{getTransforms()}, which is defined by \textbf{Node}. It is shown here:

\begin{verbatim}
final ObservableList<Transform> getTransforms()
\end{verbatim}

It returns a reference to the list of transforms. To add a transform, simply add it to this list by calling \texttt{add()}. You can clear the list by calling \texttt{clear()}. You can use \texttt{remove()} to remove a specific element.

In some cases, you can specify a transform directly, by setting one of \textbf{Node}'s properties. For example, you can set the rotation angle of a node, with the pivot point being at the center of the node, by calling \texttt{setRotate()}, passing in the desired angle. You can set a scale by using \texttt{setScaleX()} and \texttt{setScaleY()}, and you can translate a node by using \texttt{setTranslateX()} and \texttt{setTranslateY()}. (\texttt{Z} axis translations may also be supported by the platform.) However, using the transforms list offers the greatest flexibility, and that is the approach demonstrated here.

\textbf{NOTE} Any transforms specified on a node directly will be applied after all transforms in the transforms list.

To demonstrate the use of transforms, we will use the \textbf{Rotate} and \textbf{Scale} classes. The other transforms are used in the same general way. \textbf{Rotate} rotates a node around a specified point. It defines several constructors. Here is one example:
Rotate(double \textit{angle}, double \textit{x}, double \textit{y})

Here, \textit{angle} specifies the number of degrees to rotate. The center of rotation, called the \textit{pivot point}, is specified by \textit{x} and \textit{y}. It is also possible to use the default constructor and set these values after a \textbf{Rotate} object has been created, which is what the following demonstration program will do. This is done by using the \textbf{setAngle( )}, \textbf{setPivotX( )}, and \textbf{setPivotY( )} methods, shown here:

\begin{verbatim}
final void setAngle(double angle)
final void setPivotX(double x)
final void setPivotY(double y)
\end{verbatim}

As before, \textit{angle} specifies the number of degrees to rotate and the center of rotation is specified by \textit{x} and \textit{y}.

\textbf{Scale} scales a node as specified by a scale factor. \textbf{Scale} defines several constructors. This is the one we will use:

\textbf{Scale}(double \textit{widthFactor}, double \textit{heightFactor})

Here, \textit{widthFactor} specifies the scaling factor applied to the node’s width, and \textit{heightFactor} specifies the scaling factor applied to the node’s height. These factors can be changed after a \textbf{Scale} instance has been created by using \textbf{setX( )} and \textbf{setY( )}, shown here:

\begin{verbatim}
final void setX(double widthFactor)
final void setY(double heightFactor)
\end{verbatim}

As before, \textit{widthFactor} specifies the scaling factor applied to the node’s width, and \textit{heightFactor} specifies the scaling factor applied to the node’s height.

**Demonstrating Effects and Transforms**

The following program demonstrates the use of effects and transforms. It does so by creating four buttons called Rotate, Scale, Glow, and Shadow. Each time one of these buttons is pressed, the corresponding effect or transform is applied to the button. Sample output is shown here:
When you examine the program, you will see how easy it is to customize the look of your GUI. You might find it interesting to experiment with it, trying different transforms or effects, or trying the effects on different types of nodes other than buttons.

// Demonstrate rotation, scaling, glowing, and inner shadow.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;
import javafx.scene.transform.*;
import javafx.scene.effect.*;
import javafx.scene.paint.*;

public class EffectsAndTransformsDemo extends Application {

double angle = 0.0;
double glowVal = 0.0;
boolean shadow = false;
double scaleFactor = 1.0;

// Create initial effects and transforms.
Glow glow = new Glow(0.0);
InnerShadow innerShadow = new InnerShadow(10.0, Color.RED);
Rotate rotate = new Rotate();
Scale scale = new Scale(scaleFactor, scaleFactor);

// Create four push buttons.
Button btnRotate = new Button("Rotate");
Button btnGlow = new Button("Glow");
Button btnShadow = new Button("Shadow off");
Button btnScale = new Button("Scale");

public static void main(String[] args) {
    // Start the JavaFX application by calling launch().
    launch(args);
}

// Override the start() method.
public void start(Stage myStage) {

// Give the stage a title.
myStage.setTitle("Effects and Transforms Demo");

// Use a FlowPane for the root node. In this case,
// vertical and horizontal gaps of 10 are used.
FlowPane rootNode = new FlowPane(10, 10);

// Center the controls in the scene.
rootNode.setAlignment(Pos.CENTER);

// Create a scene.
Scene myScene = new Scene(rootNode, 300, 100);

// Set the scene on the stage.
myStage.setScene(myScene);

// Set the initial glow effect.
btnGlow.setEffect(glow);

// Add rotation to the transform list for the Rotate button.
btnRotate.getTransforms().add(rotate);

// Add scaling to the transform list for the Scale button.
btnScale.getTransforms().add(scale);

// Handle the action events for the Rotate button.
btnRotate.setOnAction(new EventHandler<ActionEvent>()
{
    // Your action event handler code here
});
public void handle(ActionEvent ae) {
    // Each time button is pressed, it is rotated 30 degrees
    // around its center.
    angle += 30.0;

    rotate.setAngle(angle);
    rotate.setPivotX(btnRotate.getWidth()/2);
    rotate.setPivotY(btnRotate.getHeight()/2);
}

// Handle the action events for the Scale button.
btnScale.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        // Each time button is pressed, the button's scale is changed.
        scaleFactor += 0.1;
        if(scaleFactor > 1.0) scaleFactor = 0.4;

        scale.setX(scaleFactor);
        scale.setY(scaleFactor);
    }
});
Before leaving the topic of effects and transforms, it is useful to mention that several of them are particularly pleasing when used on a Text node. Text is a class packaged in javafx.scene.text. It creates a node that consists of text. Because it is a node, the text can be easily manipulated as a unit and various effects and transforms can be applied.

Adding Tooltips
One very popular element in the modern GUI is the *tooltip*. A tooltip is a short message that is displayed when the mouse hovers over a control. In JavaFX, a tooltip can be easily added to any control. Frankly, because of the benefits that tooltips offer and the ease by which they can be incorporated into your GUI, there is virtually no reason not to use them where appropriate.

To add a tooltip, you call the `setTooltip()` method defined by `Control`. (`Control` is a base class for all controls.) The `setTooltip()` method is shown here:

```java
final void setTooltip(Tooltip tip)
```

In this case, `tip` is an instance of `Tooltip`, which specifies the tooltip. Once a tooltip has been set, it is automatically displayed when the mouse hovers over the control. No other action is required on your part.

The `Tooltip` class encapsulates a tooltip. This is the constructor that we will use:

```java
Tooltip(String str)
```

Here, `str` specifies the message that will be displayed by the tooltip.

To see tooltips in action, try adding the following statements to the `CheckboxDemo` program shown earlier.

```java
cbWeb.setTooltip(new Tooltip("Deploy to Web"));
cbDesktop.setTooltip(new Tooltip("Deploy to Desktop"));
cbMobile.setTooltip(new Tooltip("Deploy to Mobile"));
```

After these additions, the tooltips will be displayed for each check box.

**Disabling a Control**

Before leaving the subject of controls, it is useful to describe one more feature. Any node in the scene graph, including a control, can be disabled under program control. To disable a control, use `setDisable()`, defined by `Node`. It is shown here:

```java
final void setDisable(boolean disable)
```

If `disable` is true, the control is disabled; otherwise, it is enabled. Thus, using `setDisable()`, you can disable a control and then enable it later.
CHAPTER
Introducing JavaFX Menus

Menus are an important part of many GUIs because they give the user access to a program’s core functionally. Furthermore, the proper implementation of an application’s menus is a necessary part of creating a successful GUI. Because of the key role they play in many applications, JavaFX provides extensive support for menus. Fortunately, JavaFX’s approach to menus is both powerful and streamlined.

As you will see throughout the course of this chapter, JavaFX menus have several parallels with Swing menus, which were described in Chapter 33. As a result, if you already know how to create Swing menus, learning how to create menus in JavaFX is easy. That said, there are also several differences, so it is important not to jump to conclusions about the JavaFX menu system.

The JavaFX menu system supports several key elements, including

- The menu bar, which is the main menu for an application.
- The standard menu, which can contain either items to be selected or other menus (submenus).
- The context menu, which is often activated by right-clicking the mouse. Context menus are also called popup menus.

JavaFX menus also support accelerator keys, which enable menu items to be selected without having to activate the menu, and mnemonics, which allow a menu item to be selected by the keyboard once the menu options are displayed. In addition to “normal” menus, JavaFX also supports the toolbar, which provides rapid access to program functionality, often paralleling menu items.

Menu Basics

The JavaFX menu system is supported by a group of related classes packaged in javafx.scene.control. The ones used in this chapter are shown in Table 36-1, and they represent the core of the menu system. Although JavaFX allows a high degree of customization if desired, normally you will simply use the menu classes as-is because their default look and feel is generally what you will want.
Table 36-1  The Core JavaFX Menu Classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CheckMenuItem</td>
<td>A check menu item.</td>
</tr>
<tr>
<td>ContextMenu</td>
<td>A pop up menu that is typically activated by right-clicking the mouse.</td>
</tr>
<tr>
<td>Menu</td>
<td>A standard menu. A menu consists of one or more MenuItems.</td>
</tr>
<tr>
<td>MenuBar</td>
<td>An object that holds the top level menu for the application.</td>
</tr>
<tr>
<td>MenuItem</td>
<td>An object that populates menus.</td>
</tr>
<tr>
<td>RadioMenuItem</td>
<td>A radio menu item.</td>
</tr>
<tr>
<td>SeparatorMenuItem</td>
<td>A visual separator between menu items.</td>
</tr>
</tbody>
</table>

Here is brief overview of how the classes fit together. To create a main menu for an application, you first need an instance of MenuBar. This class is, loosely speaking, a container for menus. To the MenuBar you add instances of Menu. Each Menu object defines a menu. That is, each Menu object contains one or more selectable items. The items displayed by a Menu are objects of type MenuItem. Thus, a MenuItem defines a selection that can be chosen by the user.

In addition to “standard” menu items, you can also include check and radio menu items in a menu. Their operation parallels check box and radio button controls. A check menu item is created by CheckMenuItem. A radio menu item is created by RadioMenuItem. Both of these classes extend MenuItem.

SeparatorMenuItem is a convenience class that creates a separator line in a menu. It inherits CustomMenuItem, which is a class that facilitates embedding other types of controls in a menu item. CustomMenuItem extends MenuItem.

One key point about JavaFX menus is that MenuItem does not inherit Node. Thus, instances of MenuItem can only be used in a menu. They cannot be otherwise incorporated into a scene graph. However, MenuBar does inherit Node, which does allow the menu bar to be added to the scene graph.

Another key point is that MenuItem is a superclass of Menu. This allows the creation of submenus, which are, essentially, menus within menus. To create a submenu, you first create and populate a Menu object with MenuItems and then add it to another Menu object. You will see this process in action in the examples that follow.

When a menu item is selected, an action event is generated. The text associated with the selection will be the name of the selection. Thus, when using one action event handler to process all menu selections, one way you can determine which item was selected is by examining the name. Of course, you can also use separate
anonymous inner classes or lambda expressions to handle each menu item’s action events. In this case, the menu selection is already known and there is no need to examine the name to determine which item was selected.

As an alternative or adjunct to menus that descend from the menu bar, you can also create stand-alone, context menus, which pop up when activated. To create a context menu, first create an object of type `ContextMenu`. Then, add `MenuItem`s to it. A context menu is often activated by clicking the right mouse button when the mouse is over a control for which a context menu has been defined. It is important to point out that `ContextMenu` is not derived from `MenuItem`. Rather, it inherits `PopupControl`.

A feature related to the menu is the `toolbar`. In JavaFX, toolbars are supported by the `ToolBar` class. It creates a stand-alone component that is often used to provide fast access to functionality contained within the menus of the application. For example, a toolbar might provide fast access to the formatting commands supported by a word processor.

**An Overview of MenuBar, Menu, and MenuItem**

Before you can create a menu, you need to know some specifics about `MenuBar`, `Menu`, and `MenuItem`. These form the minimum set of classes needed to construct a main menu for an application. `MenuItem`s are also used by context (i.e., popup) menus. Thus, these classes form the foundation of the menu system.

**MenuBar**

`MenuBar` is essentially a container for menus. It is the control that supplies the main menu of an application. Like all JavaFX controls, it inherits `Node`. Thus, it can be added to a scene graph. `MenuBar` has two constructors. The first is the default constructor. With this constructor, initially, the menu bar will be empty, and you will need to populate it with menus prior to use. The second constructor lets you specify the initial list of menus. As a general rule, an application has one and only one menu bar.

`MenuBar` defines several methods, but often you will use only one: `getMenus()`.
It returns a list of the menus managed by the menu bar. It is to this list that you will add the menus that you create. The `getMenus()` method is shown here:

```java
final ObservableList<Menu> getMenus()
```


A `Menu` instance is added to this list of menus by calling `add()`. You can also use `addAll()` to add two or more `Menu` instances in a single call. The added menus are positioned in the bar from left to right, in the order in which they are added. If you want to add a menu at a specific location, then use this version of `add()`:

```java
void add(int idx, E menu)
```

Here, `menu` is added at the index specified by `idx`. Indexing begins at 0, with 0 being the left-most menu.

In some cases, you might want to remove a menu that is no longer needed. You can do this by calling `remove()` on the `ObservableList` returned by `getMenus()`. Here are two of its forms:

```java
boolean remove(Object menu)
E remove(int idx)
```

Here, `menu` is a reference to the menu to remove, and `idx` is the index of the menu to remove. Indexing begins at zero. The first form returns true if the item was found and removed. The second form returns a reference to the removed element.

It is sometimes useful to obtain a count of the number of items in a menu bar. To do this, call `size()` on the list returned by `getMenus()`.

---

**NOTE** Recall that `ObservableList` implements the `List` collections interface, which gives you access to all the methods defined by `List`.

Once a menu bar has been created and populated, it is added to the scene graph in the normal way.

**Menu**

`Menu` encapsulates a menu, which is populated with `MenuItem`s. As mentioned, `Menu` is derived from `MenuItem`. This means that one `Menu` can be a selection in another `Menu`. This enables one menu to be submenu of another. `Menu` defines four constructors. Perhaps the most commonly used is shown here:

```java
Menu(String name)
```

It creates a menu that has the name specified by `name`. You can specify an image along with text with this constructor:

```java
Menu(String name, Node image)
```
Here, *image* specifies the image that is displayed. In both cases, the menu is empty until menu items are added to it. A third constructor lets you specify an initial set of menu items. It is shown here:

```java
Menu(String name, Node image, MenuItem ... menuItems)
```

Finally, you don’t have to give a menu a name when it is constructed. To create an unnamed menu, you can use the default constructor:

```java
Menu()
```

In this case, you can add a name and/or image after the fact by calling `setText()` or `setGraphic()`.

Each menu maintains a list of menu items that it contains. To add an item to the menu, add items to this list. You can do this by either specifying them in the `Menu` constructor, or by adding them to the list later. To add items after a `Menu` has been constructed, first call `getItems()`, shown here:

```java
final ObservableList<MenuItem> getItems()
```

It returns the list of items currently associated with the menu. To this list, add menu items by calling either `add()` or `addAll()`. Among other actions, you can remove an item by calling `remove()` and obtain the size of the list by calling `size()`.

One other point: You can add a menu separator to the list of menu items, which is an object of type `SeparatorMenuItem`. Separators help organize long menus by allowing you to group related items together. A separator can also help set off an important item, such as the Exit selection in a menu.

### MenuItem

`MenuItem` encapsulates an element in a menu. This element can be either a selection linked to some program action, such as Save or Close, or it can cause a submenu to be displayed. `MenuItem` defines the following three constructors:

```java
MenuItem()
MenuItem(String name)
MenuItem(String name, Node image)
```

The first creates an empty menu item. The second lets you specify the name of the item, and the third enables you to include an image.

A `MenuItem` generates an action event when selected. You can register an action
event handler for such an event by calling `setOnAction()`, just as you did when handling button events. It is shown again for your convenience:

```java
final void setOnAction(EventHandler<ActionEvent> handler)
```

Here, `handler` specifies the event handler. You can fire an action event on a menu item by calling `fire()`.

`MenuItem` defines several methods. One that is often useful is `setDisable()`, which you can use to enable or disable a menu item. It is shown here:

```java
final void setDisable(boolean disable)
```

If `disable` is `true`, the menu item is disabled and cannot be selected. If `disable` is `false`, the item is enabled. Using `setDisable()`, you can turn menu items on or off, depending on program conditions.

## Create a Main Menu

As a general rule, the most commonly used menu is the main menu. This is the menu defined by the menu bar, and it is the menu that defines all (or nearly all) of the functionality of an application. As you will see, JavaFX streamlines the process of creating and managing the main menu. Here, you will see how to construct a simple main menu. Subsequent sections will show various options.

**NOTE** As a way of clearly illustrating the similarities and differences between the Swing and JavaFX menu systems, the examples in this chapter rework the menu examples from Chapter 33. If you already know Swing, you might find it helpful to compare the two different approaches.

Constructing the main menu requires several steps. Here is one approach. First, create the `MenuBar` instance that will hold the menus. Next, construct each menu that will be in the menu bar. In general, a menu is constructed by first creating a `Menu` object and then adding `MenuItem`s to it. After the menus have been created, add them to the menu bar. Then, the menu bar, itself, must be added to the scene graph. Finally, for each menu item, you must add an action event handler that responds to the action event fired when a menu item is selected.

A good way to understand the process of creating and managing menus is to work through an example. Here is a program that creates a simple menu bar that contains three menus. The first is a standard File menu that contains Open, Close, Save, and Exit selections. The second menu is called Options, and it contains two submenus
called Colors and Priority. The third menu is called Help, and it has one item: About. When a menu item is selected, the name of the selection is displayed in a label.

```java
// Demonstrate Menus

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;

public class MenuDemo extends Application {

    Label response;

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate Menus");

        // Use a BorderPane for the root node.
        BorderPane rootNode = new BorderPane();

        // Create a scene.
        Scene myScene = new Scene(rootNode, 300, 300);

        // Set the scene on the stage.
        myStage.setScene(myScene);
    }
}
```
// Create a label that will report the selection.
response = new Label("Menu Demo");

// Create the menu bar.
MenuBar mb = new MenuBar();

// Create the File menu.
Menu fileMenu = new Menu("File");
MenuItem open = new MenuItem("Open");
MenuItem close = new MenuItem("Close");
MenuItem save = new MenuItem("Save");
MenuItem exit = new MenuItem("Exit");
fileMenu.getItems().addAll(open, close, save, new SeparatorMenuItem(), exit);

// Add File menu to the menu bar.
mb.getMenus().add(fileMenu);

// Create the Options menu.
Menu optionsMenu = new Menu("Options");

// Create the Colors submenu.
Menu colorsMenu = new Menu("Colors");
MenuItem red = new MenuItem("Red");
MenuItem green = new MenuItem("Green");
MenuItem blue = new MenuItem("Blue");
colorsMenu.getItems().addAll(red, green, blue);
optionsMenu.getItems().add(colorsMenu);

// Create the Priority submenu.
Menu priorityMenu = new Menu("Priority");
MenuItem high = new MenuItem("High");
MenuItem low = new MenuItem("Low");
priorityMenu.getItems().addAll(high, low);
optionsMenu.getItems().add(priorityMenu);

// Add a separator.
optionsMenu.getItems().add(new SeparatorMenuItem());

// Create the Reset menu item.
MenuItem reset = new MenuItem("Reset");
optionsMenu.getItems().add(reset);

// Add Options menu to the menu bar.
mb.getMenus().add(optionsMenu);

// Create the Help menu.
Menu helpMenu = new Menu("Help");
MenuItem about = new MenuItem("About");
helpMenu.getItems().add(about);

// Add Help menu to the menu bar.
mb.getMenus().add(helpMenu);
// Create one event handler that will handle menu action events.
EventHandler<ActionEvent> MEHandler =
        new EventHandler<ActionEvent>() {
            public void handle(ActionEvent ae) {
                String name = ((MenuItem)ae.getTarget()).getText();

                // If Exit is chosen, the program is terminated.
                if(name.equals("Exit")) Platform.exit();

                response.setText( name + " selected");
            }
        };

// Set action event handlers for the menu items.
open.setOnAction(MEHandler);
close.setOnAction(MEHandler);
save.setOnAction(MEHandler);
exit.setOnAction(MEHandler);
red.setOnAction(MEHandler);
green.setOnAction(MEHandler);
blue.setOnAction(MEHandler);
high.setOnAction(MEHandler);
low.setOnAction(MEHandler);
reset.setOnAction(MEHandler);
about.setOnAction(MEHandler);

        // Add the menu bar to the top of the border pane and
        // the response label to the center position.
        rootNode.setTop(mb);
        rootNode.setCenter(response);

        // Show the stage and its scene.
        myStage.show();
    }
}

Sample output is shown here:
Let’s examine, in detail, how the menus in this program are created. First, note that **MenuDemo** uses a **BorderPane** instance for the root node. **BorderPane** is similar to the AWT’s **BorderLayout** discussed in Chapter 26. It defines a window that has five areas: top, bottom, left, right, and center. The following methods set the node assigned to these areas:

```java
final void setTop(Node node)
final void setBottom(Node node)
final void setLeft(Node node)
final void setRight(Node node)
final void setCenter(Node node)
```

Here, `node` specifies the element, such as a control, that will be shown in each location. Later in the program, the menu bar is positioned in the top location and a label that displays the menu selection is set to the center position. Setting the menu bar to the top position ensures that it will be shown at the top of the application and will automatically be resized to fit the horizontal width of the window. This is why **BorderPane** is used in the menu examples. Of course, other approaches, such as using a **VBox**, are also valid.

Much of the code in the program is used to construct the menu bar, its menus, and menu items, and this code warrants a close inspection. First, the menu bar is constructed and a reference to it is assigned to `mb` by this statement:
At this point, the menu bar is empty. It will be populated by the menus that follow.

Next, the File menu and its menu entries are created by this sequence:

```java
// Create the File menu.
Menu fileMenu = new Menu("File");
MenuItem open = new MenuItem("Open");
MenuItem close = new MenuItem("Close");
MenuItem save = new MenuItem("Save");
MenuItem exit = new MenuItem("Exit");

fileMenu.getItems().addAll(open, close, save, exit);

// Add File menu to the menu bar.
mb.getMenus().add(fileMenu);
```

The names Open, Close, Save, and Exit will be shown as selections in the menu. The menu entries are added to the File menu by this call to `addAll()` on the list of menu items returned by `getItems()`:

```java
fileMenu.getItems().addAll(open, close, save, exit);
```

Recall that `getItems()` returns the menu items associated with a `Menu` instance. To add menu items to a menu, you will add them to this list. Notice that a separator is used to separate visually the Exit entry from the others.

Finally, the File menu is added to the menu bar by this line:

```java
// Add File menu to the menu bar.
mb.getMenus().add(fileMenu);
```

Once the preceding code sequence completes, the menu bar will contain one entry: File. The File menu will contain four selections in this order: Open, Close, Save, and Exit.

The Options menu is constructed using the same basic process as the File menu. However, the Options menu consists of two submenus, Colors and Priority, and a Reset entry. The submenus are first constructed individually and then added to the Options menu. As explained, because `Menu` inherits `MenuItem`, a `Menu` can be added as an entry into another `Menu`. This is the way the submenus are created. The Reset item is added last. Then, the Options menu is added to the menu bar. The Help menu is constructed using the same process.

After all of the menus have been constructed, an `ActionEvent` handler called `MEHandler` is created that will process menu selections. For demonstration purposes, a single handler will process all selections, but in a real-world application, it is often easier to specify a separate handler for each individual selection by using
anonymous inner classes or lambda expressions. The `ActionEvent` handler for the menu items is shown here:

```java
// Create one event handler that will handle all menu events.
EventHandler<ActionEvent> MEHandler = new EventHandler<ActionEvent>() {

    public void handle(ActionEvent ae) {
        String name = ((MenuItem)ae.getTarget()).getText();

        // If Exit is chosen, the program is terminated.
        if (name.equals("Exit")) Platform.exit();

        response.setText( name + " selected");
    }
};
```

Inside `handle()`, the target of the event is obtained by calling `getTarget()`. The returned reference is cast to `MenuItem`, and its name is returned by calling `getText()`. This string is then assigned to `name`. If `name` contains the string "Exit", the application is terminated by calling `Platform.exit()`. Otherwise, the name is displayed in the `response` label.

Before continuing, it must be pointed out that a JavaFX application must call `Platform.exit()`, not `System.exit()`. The `Platform` class is defined by JavaFX and packaged in `javafx.application`. Its `exit()` method causes the `stop()` life-cycle method to be called. `System.exit()` does not.

Finally, `MEHandler` is registered as the action event handler for each menu item by the following statements:

```java
// Set action event handlers for the menu items.
open.setOnAction(MEHandler);
close.setOnAction(MEHandler);
save.setOnAction(MEHandler);
exit.setOnAction(MEHandler);
red.setOnAction(MEHandler);
green.setOnAction(MEHandler);
blue.setOnAction(MEHandler);
high.setOnAction(MEHandler);
low.setOnAction(MEHandler);
reset.setOnAction(MEHandler);
about.setOnAction(MEHandler);
```

Notice that no listeners are added to the Colors or Priority items because they are not actually selections. They simply activate submenus.
Finally, the menu bar is added to the root node by the following line:

```java
rootNode.setTop(mb);
```

This causes the menu bar to be placed at the top of the window.

At this point, you might want to experiment a bit with the `MenuDemo` program. Try adding another menu or adding additional items to an existing menu. It is important that you understand the basic menu concepts before moving on because this program will evolve throughout the remainder of this chapter.

## Add Mnemonics and Accelerators to Menu Items

The menu created in the preceding example is functional, but it is possible to make it better. In real applications, a menu usually includes support for keyboard shortcuts. These come in two forms: accelerators and mnemonics. An accelerator is a key combination that lets you select a menu item without having to first activate the menu. As it applies to menus, a mnemonic defines a key that lets you select an item from an active menu by typing the key. Thus, a mnemonic allows you to use the keyboard to select an item from a menu that is already being displayed.

An accelerator can be associated with a `Menu` or `MenuItem`. It is specified by calling `setAccelerator()`, shown next:

```java
final void setAccelerator(KeyCombination keyComb)
```

Here, `keyComb` is the key combination that is pressed to select the menu item. `KeyCombination` is a class that encapsulates a key combination, such as `CTRL-S`. It is packaged in `javafx.scene.input`.

`KeyCombination` defines two protected constructors, but often you will use the `keyCombination( )` factory method, shown here:

```java
static KeyCombination keyCombination(String keys)
```

In this case, `keys` is a string that specifies the key combination. It typically consists of a modifier, such as `CTRL`, `ALT`, `SHIFT`, or `META`, and a letter, such as `S`. There is a special value, called `shortcut`, which can be used to specify the `CTRL` key in a Windows system and the `META` key on a Mac. (It also maps to the typically used shortcut key on other types of systems.) Therefore, if you want to specify `CTRL-S` as the key combination for Save, then use the string "shortcut+S". This way, it will work for both Windows and Mac and elsewhere.
The following sequence adds accelerators to the File menu created by the MenuDemo program in the previous section. After making this change, you can directly select a File menu option by pressing the corresponding key.

```java
// Add keyboard accelerators for the File menu.
open.setAccelerator(KeyCombination.keyCombination("shortcut+O"));
close.setAccelerator(KeyCombination.keyCombination("shortcut+C"));
save.setAccelerator(KeyCombination.keyCombination("shortcut+S"));
exit.setAccelerator(KeyCombination.keyCombination("shortcut+E"));
```

A mnemonic can be specified for both MenuItem and Menu objects, and it is very easy to do. Simply precede the letter in the name of the menu or menu item with an underscore. For example, in the preceding example, to add the mnemonic F to the File menu, declare fileMenu as shown here:

```java
Menu fileMenu = new Menu("_File"); // now defines a mnemonic
```

After making this change, you can select the File menu by typing ALT then F. However, mnemonics are active only if mnemonic parsing is true (as it is by default). You can turn mnemonic parsing on or off by using setMnemonicParsing(), shown here:

```java
final void setMnemonicParsing(boolean enable)
```

In this case, if enable is true, then mnemonic parsing is turned on. Otherwise, it is turned off.

After making these changes, the File menu will now look like this:
Add Images to Menu Items

You can add images to menu items or use images instead of text. The easiest way to add an image is to specify it when the menu item is being constructed using this constructor:

```java
MenuItem(String name, Node image)
```

It creates a menu item with the name specified by `name` and the image specified by `image`. For example, here the About menu item is associated with an image when it is created:

```java
ImageView aboutIV = new ImageView("aboutIcon.gif");
MenuItem about = new MenuItem("About", aboutIV);
```

After this addition, the image specified by `aboutIV` will be displayed next to the text “About” when the Help menu is displayed, as shown here:
One last point: You can also add an image to a menu item after the item has been created by calling `setGraphic()` . This lets you change the image during program execution.

### Use RadioMenuItem and CheckMenuItem

Although the type of menu items used by the preceding examples are, as a general rule, the most commonly used, JavaFX defines two others: check menu items and radio menu items. These elements can streamline a GUI by allowing a menu to provide functionality that would otherwise require additional, stand-alone components. Also, sometimes including check or radio menu items simply seems most natural for a specific set of features. Whatever your reason, it is easy to use check and/or radio menu items in menus, and both are examined here.

To add a check menu item to a menu, use `CheckMenuItem` . It defines three constructors, which parallel the ones defined by `MenuItem` . The one used in this chapter is shown here:

```
CheckMenuItem(String name)
```

Here, `name` specifies the name of the item. The initial state of the item is unchecked. If you want to check a check menu item under program control, call `setSelected()` , shown here:

```
final void setSelected(boolean selected)
```
If `selected` is `true`, the menu item is checked. Otherwise, it is unchecked.

Like stand-alone check boxes, check menu items generate action events when their state is changed. Check menu items are especially appropriate in menus when you have options that can be selected and you want to display their selected/deselected status.

A radio menu item can be added to a menu by creating an object of type `RadioMenuItem`. `RadioMenuItem` defines a number of constructors. The one used in this chapter is shown here:

```java
RadioMenuItem(String name)
```

It creates a radio menu item that has the name passed in `name`. The item is not selected. As with the case of check menu items, to select a radio menu item, call `setSelected()`, passing `true` as an argument.

`RadioMenuItem` works like a stand-alone radio button, generating both change and action events. Like stand-alone radio buttons, menu radio items must be put into a toggle group in order for them to exhibit mutually exclusive selection behavior.

Because both `CheckMenuItem` and `RadioMenuItem` inherit `MenuItem`, each has all of the functionality provided by `MenuItem`. Aside from having the extra capabilities of check boxes and radio buttons, they act like and are used like other menu items.

To try check and radio menu items, first remove the code that creates the Options menu in the `MenuDemo` example program. Then substitute the following code sequence, which uses check menu items for the Colors submenu and radio menu items for the Priority submenu:
// Create the Options menu.
Menu optionsMenu = new Menu("Options");

// Create the Colors submenu.
Menu colorsMenu = new Menu("Colors");

// Use check menu items for colors. This allows
// the user to select more than one color.
CheckMenuItem red = new CheckMenuItem("Red");
CheckMenuItem green = new CheckMenuItem("Green");
CheckMenuItem blue = new CheckMenuItem("Blue");
colorsMenu.getItems().addAll(red, green, blue);
optionsMenu.getItems().add(colorsMenu);

// Select green for the default color selection.
green.setSelected(true);

// Create the Priority submenu.
Menu priorityMenu = new Menu("Priority");

// Use radio menu items for the priority setting.
// This lets the menu show which priority is used
// and also ensures that one and only one priority
// can be selected at any one time.
RadioMenuItem high = new RadioMenuItem("High");
RadioMenuItem low = new RadioMenuItem("Low");
After making the substitution, the check menu items in the Colors submenu look like those shown here:

```java
// Create a toggle group and use it for the radio menu items.
ToggleGroup tg = new ToggleGroup();
high.setToggleGroup(tg);
low.setToggleGroup(tg);

// Select High priority for the default selection.
high.setSelected(true);

// Add the radio menu items to the Priority menu and
// add the Priority menu to the Options menu.
priorityMenu.getItems().addAll(high, low);
optionsMenu.getItems().add(priorityMenu);

// Add a separator.
optionsMenu.getItems().add(new SeparatorMenuItem());

// Create the Reset menu item.
MenuItem reset = new MenuItem("Reset");
optionsMenu.getItems().add(reset);

// Add Options menu to the menu bar.
mb.getMenus().add(optionsMenu);
```
Create a Context Menu

A popular alternative or addition to the menu bar is the popup menu, which in JavaFX is referred to as a context menu. Typically, a context menu is activated by clicking the right mouse button when over a control. Popup menus are supported in JavaFX by the ContextMenu class. The direct superclass of ContextMenu is PopupControl. An indirect superclass of ContextMenu is javafx.stage.PopupWindow, which supplies much of its basic functionality.

ContextMenu has two constructors. The one used in this chapter is shown here:

ContextMenu(MenuItem … menuItems)

Here, menuItems specify the menu items that will constitute the context menu. The second ContextMenu constructor creates an empty menu to which items must be added.

In general, context menus are constructed like regular menus. Menu items are created and added to the menu. Menu item selections are also handled in the same way: by handling action events. The main difference between a context menu and a regular menu is the activation process.

To associate a context menu with a control is amazingly easy. Simply call setContextMenu( ) on the control, passing in a reference to the menu that you want
to pop up. When you right-click on that control, the associated context menu will be shown. The `setContextMenu()` method is shown here:

```java
final void setContextMenu(ContextMenu menu)
```

In this case, `menu` specifies the context menu associated with the invoking control.

To demonstrate a context menu, we will add one to the `MenuDemo` program. The context menu will present a standard “Edit” menu that includes the Cut, Copy, and Paste entries. It will be set on a text field control. When the mouse is right-clicked while in the text field, the context menu will pop up. To begin, create the context menu, as shown here:

```java
// Create the context menu items
MenuItem cut = new MenuItem("Cut");
MenuItem copy = new MenuItem("Copy");
MenuItem paste = new MenuItem("Paste");

// Create a context (i.e., popup) menu that shows edit options.
final ContextMenu editMenu = new ContextMenu(cut, copy, paste);
```

This sequence begins by constructing the `MenuItem` objects that will form the menu. It then creates an instance of `ContextMenu` called `editMenu` that contains the items.

Next, add the action event handler to these menu items, as shown here:

```java
cut.setOnAction(new MEHandler);
copy.setOnAction(new MEHandler);
paste.setOnAction(new MEHandler);
```

This finishes the construction of the context menu, but the menu has not yet been associated with a control.

Now, add the following sequence that creates the text field:

```java
// Create a text field and set its column width to 20.
TextField tf = new TextField();
tf.setPrefColumnCount(20);

Next, set the context menu on the text field:

```java
// Add the context menu to the textfield.
tf.setContextMenu(editMenu);
```

Now, when the mouse is right-clicked over the text field, the context menu will pop up.
To add the text field to the program, you must create a flow pane that will hold both the text field and the response label. This pane will then be added to the center of the **BorderPane**. This step is necessary because only one node can be added to any single location within a **BorderPane**. First, remove this line of code:

```java
rootNode.setCenter(response);
```

Replace it with the following code:

```java
// Create a flow pane that will hold both the response
// label and the text field.
FlowPane fpRoot = new FlowPane(10, 10);

// Center the controls in the scene.
fpRoot.setAlignment(Pos.CENTER);

// Add both the label and the text field to the flow pane.
fpRoot.getChildren().addAll(response, tf);

// Add the flow pane to the center of the border layout.
rootNode.setCenter(fpRoot);
```

Of course, the menu bar is still added to the top position of the border pane.

After making these changes, when you right-click over the text field, the context menu will pop up, as shown here:
It is also possible to associate a context menu with a scene. One way to do this is by calling `setOnContextMenuRequested()` on the root node of the scene. This method is defined by `Node` and is shown here:

```java
final void setOnContextMenuRequested(
    EventHandler<? super ContextMenuEvent> eventHandler)
```

Here, `eventHandler` specifies the handler that will be called when a popup request has been received for the context menu. In this case, the handler must call the `show()` method defined by `ContextMenu` to cause the context menu to be displayed. This is the version we will use:

```java
final void show(Node node, double upperX, double upperY)
```

Here, `node` is the element on which the context menu is linked. The values of `upperX` and `upperY` define the X,Y location of the upper-left corner of the menu, relative to the screen. Typically, you will pass the screen coordinates at which the right-click occurred. To do this, you will call the `getScreenX()` and `getScreenY()` methods defined by `ContextMenuEvent`. They are shown here:

```java
final double getScreenX()
final double getScreenY()
```

Thus, you will typically pass the results of these methods to the `show()` method.

The preceding theory can be put into practice by adding the context menu to the root node of the scene graph. After doing so, right-clicking anywhere in the scene will cause the menu to pop up. To do this, add the following sequence to the `MenuDemo` program:

```java
// Add the context menu to the entire scene graph.
rootNode.setOnContextMenuRequested(
    new EventHandler<ContextMenuEvent>() {
        public void handle(ContextMenuEvent ae) {
            // Popup menu at the location of the right click.
            editMenu.show(rootNode, ae.getScreenX(), ae.getScreenY());
        }
    });
```

After you have made this addition, the context menu can be activated by clicking the right mouse button anywhere inside the application scene. For example, here is the menu displayed after right-clicking in the upper-left portion of the window:
Create a Toolbar

A toolbar is a component that can serve as both an alternative and as an adjunct to a menu. Typically, a toolbar contains a list of buttons that give the user immediate access to various program options. For example, a toolbar might contain buttons that select various font options, such as bold, italics, highlight, or underline. These options can be selected without the need to drop through a menu. As a general rule, toolbar buttons show images rather than text, although either or both are allowed. Furthermore, often tooltips are associated with image-based toolbar buttons.

In JavaFX, toolbars are instances of the `ToolBar` class. It defines the two constructors, shown here:

```
ToolBar()
ToolBar(Node … nodes)
```

The first constructor creates an empty, horizontal toolbar. The second creates a horizontal toolbar that contains the specified nodes, which are usually some form of button. If you want to create a vertical toolbar, call `setOrientation()` on the toolbar. It is shown here:

```
final void setOrientation(Orientation how)
```

The value of `how` must be either `Orientation.VERTICAL` or
You add buttons (or other controls) to a toolbar in much the same way that you add them to a menu bar: call \texttt{add()} on the reference returned by the \texttt{getItems()} method. Often, however, it is easier to specify the items in the \texttt{ToolBar} constructor, and that is the approach used in this chapter. Once you have created a toolbar, add it to the scene graph. For example, when using a border layout, it could be added to the bottom location. Of course, other approaches are commonly used. For example, it could be added to a location directly under the menu bar or at the side of the window.

To illustrate a toolbar, we will add one to the \texttt{MenuDemo} program. The toolbar will present three debugging options: Set Breakpoint, Clear Breakpoint, and Resume Execution. We will also add tooltips to the menu items. Recall from the previous chapter, a tooltip is a small message that describes an item. It is automatically displayed if the mouse hovers over the item for moment. You can add a tooltip to the menu item in the same way as you add it to a control: by calling \texttt{setTooltip()}. Tooltips are especially useful when applied to image-based toolbar controls because sometimes it’s hard to design images that are intuitive to all users.

First, add the following code, which creates the debugging toolbar:

```java
// Define a toolbar. First, create toolbar items.
Button btnSet = new Button("Set Breakpoint",
                new ImageView("setBP.gif"));
Button btnClear = new Button("Clear Breakpoint",
                new ImageView("clearBP.gif"));
Button btnResume = new Button("Resume Execution",
                new ImageView("resume.gif"));

// Now, turn off text in the buttons.
btnSet.setContentDisplay(ContentDisplay.GRAPHIC_ONLY);
btnClear.setContentDisplay(ContentDisplay.GRAPHIC_ONLY);
btnResume.setContentDisplay(ContentDisplay.GRAPHIC_ONLY);

// Set tooltips.
btnSet.setToolTipText(new Tooltip("Set a breakpoint.")
btnClear.setToolTipText(new Tooltip("Clear a breakpoint.")
btnResume.setToolTipText(new Tooltip("Resume execution.")

// Create the toolbar.
ToolBar tbDebug = new ToolBar(btnSet, btnClear, btnResume);
```

Let’s look at this code closely. First, three buttons are created that correspond to the debug actions. Notice that each has an image associated with it. Next, each
button deactivates the text display by calling `setContentDisplay()`. As a point of interest, it would have been possible to leave the text displayed, but the toolbar would have had a somewhat nonstandard look. (The text for each button is still needed, however, because it will be used by the action event handler for the buttons.) Tooltips are then set for each button. Finally, the toolbar is created, with the buttons specified as the contents.

Next, add the following sequence, which defines an action event handler for the toolbar buttons:

```java
// Create a handler for the toolbar buttons.
EventHandler<ActionEvent> btnHandler = new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        response.setText(((Button)ae.getTarget()).getText());
    }
};

// Set the toolbar button action event handlers.
btnSet.setOnAction(btnHandler);
btnClear.setOnAction(btnHandler);
btnResume.setOnAction(btnHandler);
```

Finally, add the toolbar to the bottom of the border layout by using this statement:

```java
rootNode.setBottom(tbDebug);
```

After making these additions, each time the user presses a toolbar button, an action event is fired, and it is handled by displaying the button’s text in the `response` label. The following output shows the toolbar in action:
Put the Entire MenuDemo Program Together

Throughout the course of this discussion, many changes and additions have been made to the MenuDemo program shown at the start of the chapter. Before concluding, it will be helpful to assemble all the pieces. Doing so not only eliminates any ambiguity about the way the pieces fit together, but it also gives you a complete menu demonstration program that you can experiment with.

The following version of MenuDemo includes all of the additions and enhancements described in this chapter. For clarity, the program has been reorganized, with separate methods being used to construct the various menus and toolbar. Notice that several of the menu-related variables, such as mb and tbDebug, have been made into instance variables so they can be directly accessed by any part of the class.
// Demonstrate Menus -- Final Version

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;
import javafx.scene.input.*;
import javafx.scene.image.*;
import javafx.beans.value.*;

public class MenuDemoFinal extends Application {

    MenuBar mb;
    EventHandler<ActionEvent> MEHandler;
    ContextMenu editMenu;
    ToolBar tbDebug;

    Label response;

    public static void main(String[] args) {

        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate Menus -- Final Version");

        // Use a BorderPane for the root node.
        BorderPane rootNode = new BorderPane();

        // Create a scene.
        Scene myScene = new Scene(rootNode, 300, 300);
// Set the scene on the stage.
myStage.setScene(myScene);

// Create a label that will report the selection.
response = new Label();

// Create one event handler for all menu action events.
MEHandler = new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        String name = ((MenuItem)ae.getTarget()).getText();

        if(name.equals("Exit")) Platform.exit();

        response.setText(name + " selected");
    }
};

// Create the menu bar.
mb = new MenuBar();

// Create the File menu.
makeFileMenu();

// Create the Options menu.
makeOptionsMenu();

// Create the Help menu.
makeHelpMenu();
// Create the context menu.
makeContextMenu();

// Create a text field and set its column width to 20.
TextField tf = new TextField();
tf.setPrefColumnCount(20);

// Add the context menu to the text field.
tf.setContextMenu(editMenu);

// Create the toolbar.
makeToolBar();

// Add the context menu to the entire scene graph.
rootNode.setOnContextMenuRequested(
    new EventHandler<ContextMenuEvent>() {
        public void handle(ContextMenuEvent ae) {
            // Popup menu at the location of the right click.
            editMenu.show(rootNode, ae.getScreenX(), ae.getScreenY());
        }
    });

// Add the menu bar to the top of the border pane.
rootNode.setTop(mb);
// Create a flow pane that will hold both the response
// label and the text field.
FlowPane fpRoot = new FlowPane(10, 10);

// Center the controls in the scene.
fpRoot.setAlignment(Pos.CENTER);

// Use a separator to better organize the layout.
Separator separator = new Separator();
separator.setPrefWidth(260);

// Add the label, separator, and text field to the flow pane.
fpRoot.getChildren().addAll(response, separator, tf);

// Add the toolbar to the bottom of the border pane.
rootNode.setBottom(tbDebug);

// Add the flow pane to the center of the border layout.
rootNode.setCenter(fpRoot);

// Show the stage and its scene.
myStage.show();
}

// Create the File menu.
void makeFileMenu() {
    // Create the File menu, including a mnemonic.
    Menu fileMenu = new Menu("_File");
// Create the File menu items.
MenuItem open = new MenuItem("Open");
MenuItem close = new MenuItem("Close");
MenuItem save = new MenuItem("Save");
MenuItem exit = new MenuItem("Exit");

// Add items to File menu.
fileMenu.getItems().addAll(open, close, save,
    new SeparatorMenuItem(), exit);

// Add keyboard accelerators for the File menu.
open.setAccelerator(KeyCombination.getKeyCombination("shortcut+O"));
close.setAccelerator(KeyCombination.getKeyCombination("shortcut+C"));
save.setAccelerator(KeyCombination.getKeyCombination("shortcut+S"));
exit.setAccelerator(KeyCombination.getKeyCombination("shortcut+E"));

// Set action event handlers.
open.setOnAction(EventHandler);
close.setOnAction(EventHandler);
save.setOnAction(EventHandler);
exit.setOnAction(EventHandler);

// Add File menu to the menu bar.
mb.getMenus().add(fileMenu);
// Create the Options menu.
void makeOptionsMenu() {
    Menu optionsMenu = new Menu("Options");

    // Create the Colors submenu.
    Menu colorsMenu = new Menu("Colors");

    // Use check menu items for colors. This allows
    // the user to select more than one color.
    CheckMenuItem red = new CheckMenuItem("Red");
    CheckMenuItem green = new CheckMenuItem("Green");
    CheckMenuItem blue = new CheckMenuItem("Blue");

    // Add the check menu items for the Colors menu and
    // add the colors menu to the Options menu.
    colorsMenu.getItems().addAll(red, green, blue);
    optionsMenu.getItems().add(colorsMenu);

    // Select green for the default color selection.
    green.setSelected(true);

    // Create the Priority submenu.
    Menu priorityMenu = new Menu("Priority");

    // Use radio menu items for the priority setting.
    // This lets the menu show which priority is used
    // and also ensures that one and only one priority
    // can be selected at any one time.
    RadioMenuItem high = new RadioMenuItem("High");
    RadioMenuItem low = new RadioMenuItem("Low");
/ Create a toggle group and use it for the radio menu items.
ToggleGroup tg = new ToggleGroup();
high.setToggleGroup(tg);
low.setToggleGroup(tg);

// Select High priority for the default selection.
high.setSelected(true);

// Add the radio menu items to the Priority menu and
// add the Priority menu to the Options menu.
priorityMenu.getItems().addAll(high, low);
optionsMenu.getItems().add(priorityMenu);

// Add a separator.
optionsMenu.getItems().add(new SeparatorMenuItem());

// Create the Reset menu item and add it to the Options menu.
MenuItem reset = new MenuItem("Reset");
optionsMenu.getItems().add(reset);

// Set action event handlers.
red.setOnAction(MEHandler);
green.setOnAction(MEHandler);
blue.setOnAction(MEHandler);
high.setOnAction(MEHandler);
low.setOnAction(MEHandler);
reset.setOnAction(MEHandler);

// Use a change listener to respond to changes in the radio
// menu item setting.
tg.selectedToggleProperty().addListener(new ChangeListener<Toggle>() {
    public void changed(ObservableValue<? extends Toggle> oldVal, Toggle newVal) {
        if (newVal == null) return;

        // Cast newVal to RadioButton.
        RadioMenuItem rmi = (RadioMenuItem) newVal;

        // Display the selection.
        response.setText("Priority selected is " + rmi.getText());
    }
});

// Add Options menu to the menu bar.
mb.getMenus().add(optionsMenu);

// Create the Help menu.
void makeHelpMenu() {

    // Create an ImageView for the image.
    ImageView aboutIV = new ImageView("aboutIcon.gif");
// Create the Help menu.
Menu helpMenu = new Menu("Help");

// Create the About menu item and add it to the Help menu.
MenuItem about = new MenuItem("About", aboutIV);
helpMenu.getItems().add(about);

// Set action event handler.
about.setOnAction(MEHandler);

// Add Help menu to the menu bar.
mb.getMenus().add(helpMenu);

// Create the context menu items.
void makeContextMenu() {

    // Create the edit context menu items.
    MenuItem cut = new MenuItem("Cut");
    MenuItem copy = new MenuItem("Copy");
    MenuItem paste = new MenuItem("Paste");

    // Create a context (i.e., popup) menu that shows edit options.
    editMenu = new ContextMenu(cut, copy, paste);
// Set the action event handlers.
cut.setOnAction(�EHandler);
copy.setOnAction(�EHandler);
paste.setOnAction(�EHandler);
}

// Create the toolbar.
void makeToolBar() {
  // Create toolbar items.
  Button btnSet = new Button("Set Breakpoint",
      new ImageView("setBP.gif"));
  Button btnClear = new Button("Clear Breakpoint",
      new ImageView("clearBP.gif"));
  Button btnResume = new Button("Resume Execution",
      new ImageView("resume.gif"));

  // Turn off text in the buttons.
  btnSet.setContentDisplay(ContentDisplay.GRAPHIC_ONLY);
  btnClear.setContentDisplay(ContentDisplay.GRAPHIC_ONLY);
  btnResume.setContentDisplay(ContentDisplay.GRAPHIC_ONLY);

  // Set tooltips.
  btnSet.setToolTipText(new Tooltip("Set a breakpoint."));
  btnClear.setToolTipText(new Tooltip("Clear a breakpoint."));
  btnResume.setToolTipText(new Tooltip("Resume execution."));)

  // Create the toolbar.
  tbDebug = new ToolBar(btnSet, btnClear, btnResume);

  // Create a handler for the toolbar buttons.
  EventHandler<ActionEvent> btnHandler = new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
      response.setText(((Button)ae.getTarget()).getText());
    }
  };

  // Set the toolbar button action event handlers.
  btnSet.setOnAction(btnHandler);
  btnClear.setOnAction(btnHandler);
  btnResume.setOnAction(btnHandler);
}
Continuing Your Exploration of JavaFX

JavaFX represents a major advance in GUI frameworks for Java. It also redefines aspects of the Java platform. The preceding three chapters have introduced several of its core features, but there is much left to explore. For example, JavaFX supplies several more controls, such as sliders, stand-alone scroll bars, and tables. You will want to experiment with its layouts, such as VBox and HBox. You will also want to explore, in detail, the various effects in javafx.scene.effect and the various transforms in javafx.scene.transform. Another exciting class is WebView, which gives you an easy way to integrate web content into a scene graph. Frankly, all of JavaFX is worthy of serious study. In many ways, it is charting the future course of Java.
PART
V Applying Java

CHAPTER 37
Java Beans

CHAPTER 38
Introducing Servlets
CHAPTER
This chapter provides an overview of Java Beans. Beans are important because they allow you to build complex systems from software components. These components may be provided by you or supplied by one or more different vendors. Java Beans defines an architecture that specifies how these building blocks can operate together.

To better understand the value of Beans, consider the following. Hardware designers have a wide variety of components that can be integrated together to construct a system. Resistors, capacitors, and inductors are examples of simple building blocks. Integrated circuits provide more advanced functionality. All of these different parts can be reused. It is not necessary or possible to rebuild these capabilities each time a new system is needed. Also, the same pieces can be used in different types of circuits. This is possible because the behavior of these components is understood and documented.

The software industry also sought the benefits of reusability and interoperability of a component-based approach. To realize these benefits, a component architecture is needed that allows programs to be assembled from software building blocks, perhaps provided by different vendors. It must also be possible for a designer to select a component, understand its capabilities, and incorporate it into an application. When a new version of a component becomes available, it should be easy to incorporate this functionality into existing code. Java Beans provides just such an architecture.

What Is a Java Bean?

A Java Bean is a software component that has been designed to be reusable in a variety of different environments. There is no restriction on the capability of a Bean. It may perform a simple function, such as obtaining an inventory value, or a complex function, such as forecasting the performance of a stock portfolio. A Bean may be visible to an end user. One example of this is a button on a graphical user interface. A Bean may also be invisible to a user. Software to decode a stream of multimedia information in real time is an example of this type of building block. Finally, a Bean may be designed to work autonomously on a user’s workstation or to work in cooperation with a set of other distributed components. Software to generate a pie chart from a set of data points is an example of a Bean that can execute locally.
However, a Bean that provides real-time price information from a stock or commodities exchange would need to work in cooperation with other distributed software to obtain its data.

**Advantages of Java Beans**

The following list enumerates some of the benefits that Java Bean technology provides for a component developer:

- A Bean obtains all the benefits of Java’s “write-once, run-anywhere” paradigm.
- The properties, events, and methods of a Bean that are exposed to another application can be controlled.
- Auxiliary software can be provided to help configure a Bean. This software is only needed when the design-time parameters for that component are being set. It does not need to be included in the run-time environment.
- The state of a Bean can be saved in persistent storage and restored at a later time.
- A Bean may register to receive events from other objects and can generate events that are sent to other objects.

**Introspection**

At the core of Java Beans is *introspection*. This is the process of analyzing a Bean to determine its capabilities. This is an essential feature of the Java Beans API because it allows another application, such as a design tool, to obtain information about a component. Without introspection, the Java Beans technology could not operate.

There are two ways in which the developer of a Bean can indicate which of its properties, events, and methods should be exposed. With the first method, simple naming conventions are used. These allow the introspection mechanisms to infer information about a Bean. In the second way, an additional class that extends the `BeanInfo` interface is provided that explicitly supplies this information. Both approaches are examined here.

**Design Patterns for Properties**

A *property* is a subset of a Bean’s state. The values assigned to the properties determine the behavior and appearance of that component. A property is set through a *setter* method. A property is obtained by a *getter* method. There are two types of
properties: simple and indexed.

**Simple Properties**
A simple property has a single value. It can be identified by the following design patterns, where \( N \) is the name of the property and \( T \) is its type:

```java
public T getN()
public void setN(T arg)
```

A read/write property has both of these methods to access its values. A read-only property has only a get method. A write-only property has only a set method.

Here are three read/write simple properties along with their getter and setter methods:

```java
private double depth, height, width;

public double getDepth() {
    return depth;
}
public void setDepth(double d) {
    depth = d;
}

public double getHeight() {
    return height;
}
public void setHeight(double h) {
    height = h;
}

public double getWidth() {
    return width;
}
public void setWidth(double w) {
    width = w;
}
```

**NOTE** For a boolean property, a method of the form `isPropertyName()` can also be used as an accessor.

**Indexed Properties**
An indexed property consists of multiple values. It can be identified by the following
design patterns, where \( N \) is the name of the property and \( T \) is its type:

```java
public T getN(int index);
public void setN(int index, T value);
public T[] getN();
public void setN(T values[]);
```

Here is an indexed property called \textbf{data} along with its getter and setter methods:

```java
private double data[];

public double getData(int index) {
    return data[index];
}
public void setData(int index, double value) {
    data[index] = value;
}
public double[] getData() {
    return data;
}
public void setData(double[] values) {
    data = new double[values.length];
    System.arraycopy(values, 0, data, 0, values.length);
}
```

### Design Patterns for Events

Beans use the delegation event model that was discussed earlier in this book. Beans can generate events and send them to other objects. These can be identified by the following design patterns, where \( T \) is the type of the event:

```java
public void addTListener(TListener eventListener)
    throws java.util.TooManyListenersException
public void removeTListener(TListener eventListener)
```

These methods are used to add or remove a listener for the specified event. The version of \texttt{addTListener( )} that does not throw an exception can be used to \texttt{multicast} an event, which means that more than one listener can register for the event.
notification. The version that throws `TooManyListenersException` unicasts the event, which means that the number of listeners can be restricted to one. In either case, `removeTListener()` is used to remove the listener. For example, assuming an event interface type called `TemperatureListener`, a Bean that monitors temperature might supply the following methods:

```java
public void addTemperatureListener(TemperatureListener tl) {
    ...}
public void removeTemperatureListener(TemperatureListener tl) {
    ...}
```

**Methods and Design Patterns**

Design patterns are not used for naming nonproperty methods. The introspection mechanism finds all of the public methods of a Bean. Protected and private methods are not presented.

**Using the BeanInfo Interface**

As the preceding discussion shows, design patterns *implicitly* determine what information is available to the user of a Bean. The `BeanInfo` interface enables you to *explicitly* control what information is available. The `BeanInfo` interface defines several methods, including these:

- `PropertyDescriptor[ ] getPropertyDescriptors( )`
- `EventSetDescriptor[ ] getEventSetDescriptors( )`
- `MethodDescriptor[ ] getMethodDescriptors( )`

They return arrays of objects that provide information about the properties, events, and methods of a Bean. The classes `PropertyDescriptor`, `EventSetDescriptor`, and `MethodDescriptor` are defined within the `java.beans` package, and they describe the indicated elements. By implementing these methods, a developer can designate exactly what is presented to a user, bypassing introspection based on design patterns.

When creating a class that implements `BeanInfo`, you must call that class `bnameBeanInfo`, where `bname` is the name of the Bean. For example, if the Bean is called `MyBean`, then the information class must be called `MyBeanBeanInfo`.

To simplify the use of `BeanInfo`, JavaBeans supplies the `SimpleBeanInfo` class. It provides default implementations of the `BeanInfo` interface, including the three methods just shown. You can extend this class and override one or more of the
methods to explicitly control what aspects of a Bean are exposed. If you don’t override a method, then design-pattern introspection will be used. For example, if you don’t override `getPropertyDescriptors()`), then design patterns are used to discover a Bean’s properties. You will see SimpleBeanInfo in action later in this chapter.

**Bound and Constrained Properties**

A Bean that has a *bound* property generates an event when the property is changed. The event is of type `PropertyChangeEvent` and is sent to objects that previously registered an interest in receiving such notifications. A class that handles this event must implement the `PropertyChangeListener` interface.

A Bean that has a *constrained* property generates an event when an attempt is made to change its value. It also generates an event of type `PropertyChangeEvent`. It too is sent to objects that previously registered an interest in receiving such notifications. However, those other objects have the ability to veto the proposed change by throwing a `PropertyVetoException`. This capability allows a Bean to operate differently according to its run-time environment. A class that handles this event must implement the `VetoableChangeListener` interface.

**Persistence**

*Persistence* is the ability to save the current state of a Bean, including the values of a Bean’s properties and instance variables, to nonvolatile storage and to retrieve them at a later time. The object serialization capabilities provided by the Java class libraries are used to provide persistence for Beans.

The easiest way to serialize a Bean is to have it implement the `java.io.Serializable` interface, which is simply a marker interface. Implementing `java.io.Serializable` makes serialization automatic. Your Bean need take no other action. Automatic serialization can also be inherited. Therefore, if any superclass of a Bean implements `java.io.Serializable`, then automatic serialization is obtained.

When using automatic serialization, you can selectively prevent a field from being saved through the use of the `transient` keyword. Thus, data members of a Bean specified as `transient` will not be serialized.

If a Bean does not implement `java.io.Serializable`, you must provide serialization yourself, such as by implementing `java.io.Externalizable`. Otherwise, containers cannot save the configuration of your component.

**Customizers**
A Bean developer can provide a *customizer* that helps another developer configure the Bean. A customizer can provide a step-by-step guide through the process that must be followed to use the component in a specific context. Online documentation can also be provided. A Bean developer has great flexibility to develop a customizer that can differentiate his or her product in the marketplace.

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AppletInitializer</td>
<td>Methods in this interface are used to initialize Beans that are also applets. (Deprecated by JDK 9.)</td>
</tr>
<tr>
<td>BeanInfo</td>
<td>This interface allows a designer to specify information about the properties, events, and methods of a Bean.</td>
</tr>
<tr>
<td>Customizer</td>
<td>This interface allows a designer to provide a graphical user interface through which a Bean may be configured.</td>
</tr>
<tr>
<td>DesignMode</td>
<td>Methods in this interface determine if a Bean is executing in design mode.</td>
</tr>
<tr>
<td>ExceptionListener</td>
<td>A method in this interface is invoked when an exception has occurred.</td>
</tr>
<tr>
<td>PropertyChangeListener</td>
<td>A method in this interface is invoked when a bound property is changed.</td>
</tr>
<tr>
<td>PropertyEditor</td>
<td>Objects that implement this interface allow designers to change and display property values.</td>
</tr>
<tr>
<td>VetoableChangeListener</td>
<td>A method in this interface is invoked when a constrained property is changed.</td>
</tr>
<tr>
<td>Visibility</td>
<td>Methods in this interface allow a Bean to execute in environments where a graphical user interface is not available.</td>
</tr>
</tbody>
</table>

**Table 37-1** The Interfaces in *java.beans*

**The Java Beans API**

The Java Beans functionality is provided by a set of classes and interfaces in the *java.beans* package. Beginning with JDK 9, this package is in the *java.desktop* module. This section provides a brief overview of its contents. **Table 37-1** lists the interfaces in *java.beans* and provides a brief description of their functionality. **Table 37-2** lists the classes in *java.beans*. 
<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BeanDescriptor</td>
<td>This class provides information about a Bean. It also allows you to associate a customizer with a Bean.</td>
</tr>
<tr>
<td>Beans</td>
<td>This class is used to obtain information about a Bean.</td>
</tr>
<tr>
<td>DefaultPersistenceDelegate</td>
<td>A concrete subclass of PersistenceDelegate.</td>
</tr>
<tr>
<td>Encoder</td>
<td>Encodes the state of a set of Beans. Can be used to write this information to a stream.</td>
</tr>
<tr>
<td>EventHandler</td>
<td>Supports dynamic event listener creation.</td>
</tr>
<tr>
<td>EventSetDescriptor</td>
<td>Instances of this class describe an event that can be generated by a Bean.</td>
</tr>
<tr>
<td>Expression</td>
<td>Encapsulates a call to a method that returns a result.</td>
</tr>
<tr>
<td>FeatureDescriptor</td>
<td>This is the superclass of the PropertyDescriptor, EventSetDescriptor, and MethodDescriptor classes, among others.</td>
</tr>
<tr>
<td>Class</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><code>IndexedPropertyChangeEvent</code></td>
<td>A subclass of <code>PropertyChangeEvent</code> that represents a change to an indexed property.</td>
</tr>
<tr>
<td><code>IndexedPropertyDescriptor</code></td>
<td>Instances of this class describe an indexed property of a Bean.</td>
</tr>
<tr>
<td><code>IntrospectionException</code></td>
<td>An exception of this type is generated if a problem occurs when analyzing a Bean.</td>
</tr>
<tr>
<td><code>Introspector</code></td>
<td>This class analyzes a Bean and constructs a <code>BeanInfo</code> object that describes the component.</td>
</tr>
<tr>
<td><code>MethodDescriptor</code></td>
<td>Instances of this class describe a method of a Bean.</td>
</tr>
<tr>
<td><code>ParameterDescriptor</code></td>
<td>Instances of this class describe a method parameter.</td>
</tr>
<tr>
<td><code>PersistenceDelegate</code></td>
<td>Handles the state information of an object.</td>
</tr>
<tr>
<td><code>PropertyChangeEvent</code></td>
<td>This event is generated when bound or constrained properties are changed. It is sent to objects that registered an interest in these events and that implement either the <code>PropertyChangeListener</code> or <code>VetoableChangeListener</code> interfaces.</td>
</tr>
<tr>
<td><code>PropertyChangeListenerProxy</code></td>
<td>Extends <code>EventListenerProxy</code> and implements <code>PropertyChangeListener</code>.</td>
</tr>
<tr>
<td><code>PropertyChangeSupport</code></td>
<td>Beans that support bound properties can use this class to notify <code>PropertyChangeListener</code> objects.</td>
</tr>
<tr>
<td><code>PropertyDescriptor</code></td>
<td>Instances of this class describe a property of a Bean.</td>
</tr>
<tr>
<td><code>PropertyEditorManager</code></td>
<td>This class locates a <code>PropertyEditor</code> object for a given type.</td>
</tr>
<tr>
<td><code>PropertyEditorSupport</code></td>
<td>This class provides functionality that can be used when writing property editors.</td>
</tr>
<tr>
<td><code>PropertyVetoException</code></td>
<td>An exception of this type is generated if a change to a constrained property is vetoed.</td>
</tr>
<tr>
<td><code>SimpleBeanInfo</code></td>
<td>This class provides functionality that can be used when writing <code>BeanInfo</code> classes.</td>
</tr>
<tr>
<td><code>Statement</code></td>
<td>Encapsulates a call to a method.</td>
</tr>
<tr>
<td><code>VetoableChangeListenerProxy</code></td>
<td>Extends <code>EventListenerProxy</code> and implements <code>VetoableChangeListener</code>.</td>
</tr>
<tr>
<td><code>VetoableChangeSupport</code></td>
<td>Beans that support constrained properties can use this class to notify <code>VetoableChangeListener</code> objects.</td>
</tr>
<tr>
<td><code>XMLDecoder</code></td>
<td>Used to read a Bean from an XML document.</td>
</tr>
<tr>
<td><code>XMLEncoder</code></td>
<td>Used to write a Bean to an XML document.</td>
</tr>
</tbody>
</table>

Table 37-2  The Classes in `java.beans`
Although it is beyond the scope of this chapter to discuss all of the classes, four are of particular interest: **Introspector**, **PropertyDescriptor**, **EventSetDescriptor**, and **MethodDescriptor**. Each is briefly examined here.

**Introspector**

The **Introspector** class provides several static methods that support introspection. Of most interest is **getBeanInfo()**. This method returns a **BeanInfo** object that can be used to obtain information about the Bean. The **getBeanInfo()** method has several forms, including the one shown here:

```java
static BeanInfo getBeanInfo(Class<?> bean) throws IntrospectionException
```

The returned object contains information about the Bean specified by `bean`.

**PropertyDescriptor**

The **PropertyDescriptor** class describes the characteristics of a Bean property. It supports several methods that manage and describe properties. For example, you can determine if a property is bound by calling **isBound()**. To determine if a property is constrained, call **isConstrained()**. You can obtain the name of a property by calling **getName()**.

**EventSetDescriptor**

The **EventSetDescriptor** class represents a set of Bean events. It supports several methods that obtain the methods that a Bean uses to add or remove event listeners, and to otherwise manage events. For example, to obtain the method used to add listeners, call **getAddListenerMethod()**. To obtain the method used to remove listeners, call **getRemoveListenerMethod()**. To obtain the type of a listener, call **getListenerType()**. You can obtain the name of an event set by calling **getName()**.

**MethodDescriptor**

The **MethodDescriptor** class represents a Bean method. To obtain the name of the method, call **getName()**. You can obtain information about the method by calling **getMethod()**, shown here:

```java
Method getMethod()
```

An object of type **Method** that describes the method is returned.
A Bean Example

This chapter concludes with an example that illustrates various aspects of Bean programming, including introspection and using a BeanInfo class. It also makes use of the Introspector, PropertyDescriptor, and EventSetDescriptor classes. The example uses three classes. The first is a Bean called Colors, shown here:

```java
// A simple Bean.
import java.awt.*;
import java.awt.event.*;
import java.io.Serializable;

public class Colors extends Canvas implements Serializable {
    transient private Color color; // not persistent
    private boolean rectangular; // is persistent

    public Colors() {
        addMouseListener(new MouseAdapter() {
            public void mousePressed(MouseEvent me) {
                change();
            }
        });
        rectangular = false;
        setSize(200, 100);
        change();
    }

    public boolean getRectangular() {
        return rectangular;
    }

    public void setRectangular(boolean flag) {
        this.rectangular = flag;
        repaint();
    }

    public void change() {
        color = randomColor();
        repaint();
    }
```
private Color randomColor() {
    int r = (int)(255*Math.random());
    int g = (int)(255*Math.random());
    int b = (int)(255*Math.random());
    return new Color(r, g, b);
}

public void paint(Graphics g) {
    Dimension d = getSize();
    int h = d.height;
    int w = d.width;
    g.setColor(color);
    if(rectangular) {
        g.fillRect(0, 0, w-1, h-1);
    } else {
        g.fillOval(0, 0, w-1, h-1);
    }
}

The **Colors** Bean displays a colored object within a frame. The color of the component is determined by the private **Color** variable **color**, and its shape is determined by the private **boolean** variable **rectangular**. The constructor defines an anonymous inner class that extends **MouseAdapter** and overrides its **mousePressed()** method. The **change()** method is invoked in response to mouse presses. It selects a random color and then repaints the component. The **getRectangular()** and **setRectangular()** methods provide access to the one property of this Bean. The **change()** method calls **randomColor()** to choose a color and then calls **repaint()** to make the change visible. Notice that the **paint()** method uses the **rectangular** and **color** variables to determine how to present the Bean.

The next class is **ColorsBeanInfo**. It is a subclass of **SimpleBeanInfo** that provides explicit information about **Colors**. It overrides **getPropertyDescriptors()** in order to designate which properties are presented to a Bean user. In this case, the only property exposed is **rectangular**. The method creates and returns a **PropertyDescriptor** object for the **rectangular** property. The **PropertyDescriptor** constructor that is used is shown here:

    PropertyDescriptor(String property, Class<?> beanCls) throws
                        IntrospectionException

Here, the first argument is the name of the property, and the second argument is the
class of the Bean.

// A Bean information class.
import java.beans.*;
public class ColorsBeanInfo extends SimpleBeanInfo {
    public PropertyDescriptor[] getPropertyDescriptors() {
        try {
            PropertyDescriptor rectangular = new
                PropertyDescriptor("rectangular", Colors.class);
            PropertyDescriptor pd[] = {rectangular};
            return pd;
        }
        catch(Exception e) {
            System.out.println("Exception caught. " + e);
        }
        return null;
    }
}

The final class is called IntrospectorDemo. It uses introspection to display the properties and events that are available within the Colors Bean.

// Show properties and events.
import java.awt.*;
import java.beans.*;

public class IntrospectorDemo {
    public static void main(String args[]) {
        try {
            Class<?> c = Class.forName("Colors");
            BeanInfo beanInfo = Introspector.getBeanInfo(c);

            System.out.println("Properties:");
            PropertyDescriptor propertyDescriptor[] =
                beanInfo.getPropertyDescriptors();
            for(int i = 0; i < propertyDescriptor.length; i++) {
                System.out.println("\t" + propertyDescriptor[i].getName());
            }
        }
    }
}
System.out.println("Events:");
EventSetDescriptor eventSetDescriptor[] =
    beanInfo.getEventSetDescriptors();
for(int i = 0; i < eventSetDescriptor.length; i++) {
    System.out.println("\t" + eventSetDescriptor[i].getName());
}
}
catch(Exception e) {
    System.out.println("Exception caught. " + e);
}
}

The output from this program is the following:

Properties:
    rectangular
Events:
    mouseWheel
    mouse
    mouseMotion
    component
    hierarchyBounds
    focus
    hierarchy
    propertyChange
    inputMethod
    key

Notice two things in the output. First, because ColorsBeanInfo overrides
getPropertyDescriptors( ) such that the only property returned is rectangular, only
the rectangular property is displayed. However, because getEventSetDescriptors( )
is not overridden by ColorsBeanInfo, design-pattern introspection is used, and all
events are found, including those in Colors’ superclass, Canvas. Remember, if you
don’t override one of the “get” methods defined by SimpleBeanInfo, then the
default, design-pattern introspection is used. To observe the difference that
ColorsBeanInfo makes, erase its class file and then run IntrospectorDemo again.
This time it will report more properties.
CHAPTER
This chapter presents an introduction to *servlets*. Servlets are small programs that execute on the server side of a web connection. The topic of servlets is quite large, and it is beyond the scope of this chapter to cover it all. Instead, we will focus on the core concepts, interfaces, and classes, and develop several examples.

**Background**

In order to understand the advantages of servlets, you must have a basic understanding of how web browsers and servers cooperate to provide content to a user. Consider a request for a static web page. A user enters a Uniform Resource Locator (URL) into a browser. The browser generates an HTTP request to the appropriate web server. The web server maps this request to a specific file. That file is returned in an HTTP response to the browser. The HTTP header in the response indicates the type of the content. The Multipurpose Internet Mail Extensions (MIME) are used for this purpose. For example, ordinary ASCII text has a MIME type of text/plain. The Hypertext Markup Language (HTML) source code of a web page has a MIME type of text/html.

Now consider dynamic content. Assume that an online store uses a database to store information about its business. This would include items for sale, prices, availability, orders, and so forth. It wishes to make this information accessible to customers via web pages. The contents of those web pages must be dynamically generated to reflect the latest information in the database.

In the early days of the Web, a server could dynamically construct a page by creating a separate process to handle each client request. The process would open connections to one or more databases in order to obtain the necessary information. It communicated with the web server via an interface known as the Common Gateway Interface (CGI). CGI allowed the separate process to read data from the HTTP request and write data to the HTTP response. A variety of different languages were used to build CGI programs. These included C, C++, and Perl.

However, CGI suffered serious performance problems. It was expensive in terms of processor and memory resources to create a separate process for each client request. It was also expensive to open and close database connections for each client request. In addition, the CGI programs were not platform-independent. Therefore,
other techniques were introduced. Among these are servlets.

Servlets offer several advantages in comparison with CGI. First, performance is significantly better. Servlets execute within the address space of a web server. It is not necessary to create a separate process to handle each client request. Second, servlets are platform-independent because they are written in Java. Third, the Java security manager on the server enforces a set of restrictions to protect the resources on a server machine. Finally, the full functionality of the Java class libraries is available to a servlet. It can communicate with other software via the sockets and RMI mechanisms that you have seen already.

**The Life Cycle of a Servlet**

Three methods are central to the life cycle of a servlet. These are `init( )`, `service( )`, and `destroy( )`. They are implemented by every servlet and are invoked at specific times by the server. Let us consider a typical user scenario to understand when these methods are called.

First, assume that a user enters a Uniform Resource Locator (URL) to a web browser. The browser then generates an HTTP request for this URL. This request is then sent to the appropriate server.

Second, this HTTP request is received by the web server. The server maps this request to a particular servlet. The servlet is dynamically retrieved and loaded into the address space of the server.

Third, the server invokes the `init( )` method of the servlet. This method is invoked only when the servlet is first loaded into memory. It is possible to pass initialization parameters to the servlet so it may configure itself.

Fourth, the server invokes the `service( )` method of the servlet. This method is called to process the HTTP request. You will see that it is possible for the servlet to read data that has been provided in the HTTP request. It may also formulate an HTTP response for the client.

The servlet remains in the server’s address space and is available to process any other HTTP requests received from clients. The `service( )` method is called for each HTTP request.

Finally, the server may decide to unload the servlet from its memory. The algorithms by which this determination is made are specific to each server. The server calls the `destroy( )` method to relinquish any resources such as file handles that are allocated for the servlet. Important data may be saved to a persistent store. The memory allocated for the servlet and its objects can then be garbage collected.
Servlet Development Options

To experiment with servlets, you will need access to a servlet container/server. Two popular ones are Glassfish and Apache Tomcat. Glassfish is an open source project sponsored by Oracle and is provided by the Java EE SDK. It is supported by NetBeans. Apache Tomcat is an open-source product maintained by the Apache Software Foundation. It can also be used by NetBeans. Both Tomcat and Glassfish can also be used with other IDEs, such as Eclipse.

Although IDEs such as NetBeans and Eclipse are very useful and can streamline the creation of servlets, they are not used in this chapter. The way you develop and deploy servlets differs among IDEs, and it is simply not possible for this book to address each environment. Furthermore, many readers will be using the command-line tools rather than an IDE. Therefore, if you are using an IDE, you must refer to the instructions for that environment for information concerning the development and deployment of servlets. For this reason, the instructions given here and elsewhere in this chapter assume that only the command-line tools are employed. Thus, they will work for nearly any reader.

This chapter uses Tomcat in the examples. It provides a simple, yet effective way to experiment with servlets using only the command line tools. It is also widely available in various programming environments. Furthermore, since only command-line tools are used, you don’t need to download and install an IDE just to experiment with servlets. Understand, however, that even if you are developing in an environment that uses a different servlet container, the concepts presented here still apply. It is just that the mechanics of preparing a servlet for testing will be slightly different.

**REMEMBER** The instructions for developing and deploying servlets in this chapter are based on Tomcat and use only command-line tools. If you are using an IDE and/or a different servlet container/server, consult the documentation for your environment.

**Using Tomcat**

Tomcat contains the class libraries, documentation, and run-time support that you will need to create and test servlets. At the time of this writing, several versions of Tomcat are available. The instructions that follow use 8.5.5. You can download Tomcat from [tomcat.apache.org](http://tomcat.apache.org). You should choose a version appropriate to your environment.

The examples in this chapter assume a 64-bit Windows environment. Assuming
that a 64-bit version of Tomcat 8.5.5 was unpacked from the root directly, the default location is

C:\apache-tomcat-8.5.5-windows-x64\apache-tomcat-8.5.5\*

This is the location assumed by the examples in this book. If you load Tomcat in a different location (or use a different version of Tomcat), you will need to make appropriate changes to the examples. You may need to set the environmental variable JAVA_HOME to the top-level directory in which the Java Development Kit is installed.

NOTE All of the directories shown in this section assume Tomcat 8.5.5. If you install a different version of Tomcat, then you will need to adjust the directory names and paths to match those used by the version you installed.

Once installed, you start Tomcat by selecting startup.bat from the bin directory. To stop Tomcat, execute shutdown.bat, also in the bin directory.

The classes and interfaces needed to build servlets are contained in servlet-api.jar, which is in the following directory:

C:\apache-tomcat-8.5.5-windows-x64\apache-tomcat-8.5.5\lib

To make servlet-api.jar accessible, update your CLASSPATH environment variable so that it includes

C:\apache-tomcat-8.5.5-windows-x64\apache-tomcat-8.5.5\lib\servlet-api.jar

Alternatively, you can specify this file when you compile the servlets. For example, the following command compiles the first servlet example:

javac HelloServlet.java -classpath "C:\apache-tomcat-8.5.5-windows-x64\apache-tomcat-8.5.5\lib\servlet-api.jar"

Once you have compiled a servlet, you must enable Tomcat to find it. For our purposes, this means putting it into a directory under Tomcat’s webapps directory and entering its name into a web.xml file. To keep things simple, the examples in this chapter use the directory and web.xml file that Tomcat supplies for its own example servlets. This way, you won’t have to create any files or directories just to experiment with the sample servlets. Here is the procedure that you will follow.

First, copy the servlet’s class file into the following directory:
A Simple Servlet

To become familiar with the key servlet concepts, we will begin by building and testing a simple servlet. The basic steps are the following:

1. Create and compile the servlet source code. Then, copy the servlet’s class file to the proper directory, and add the servlet’s name and mappings to the proper web.xml file.
2. Start Tomcat.
3. Start a web browser and request the servlet.

Let us examine each of these steps in detail.
To begin, create a file named **HelloServlet.java** that contains the following program:

```java
import java.io.*;
import javax.servlet.*;

public class HelloServlet extends GenericServlet {

    public void service(ServletRequest request,
                        ServletResponse response)
        throws ServletException, IOException {
        response.setContentType("text/html");
        PrintWriter pw = response.getWriter();
        pw.println("<B>Hello!"'];?></p>
        pw.close();
    }
}
```

Let’s look closely at this program. First, note that it imports the **javax.servlet** package. This package contains the classes and interfaces required to build servlets. You will learn more about these later in this chapter. Next, the program defines **HelloServlet** as a subclass of **GenericServlet**. The **GenericServlet** class provides functionality that simplifies the creation of a servlet. For example, it provides versions of **init()** and **destroy()**, which may be used as is. You need supply only the **service()** method.

Inside **HelloServlet**, the **service()** method (which is inherited from **GenericServlet**) is overridden. This method handles requests from a client. Notice that the first argument is a **ServletRequest** object. This enables the servlet to read data that is provided via the client request. The second argument is a **ServletResponse** object. This enables the servlet to formulate a response for the client.

The call to **setContentType()** establishes the MIME type of the HTTP response. In this program, the MIME type is text/html. This indicates that the browser should interpret the content as HTML source code.

Next, the **getWriter()** method obtains a **PrintWriter**. Anything written to this stream is sent to the client as part of the HTTP response. Then **println()** is used to write some simple HTML source code as the HTTP response.

Compile this source code and place the **HelloServlet.class** file in the proper Tomcat directory as described in the previous section. Also, add **HelloServlet** to the **web.xml** file, as described earlier.

**Start Tomcat**
Start Tomcat as explained earlier. Tomcat must be running before you try to execute a servlet.

**Start a Web Browser and Request the Servlet**

Start a web browser and enter the URL shown here:

http://localhost:8080/examples/servlets/servlet/HelloServlet

Alternatively, you may enter the URL shown here:

http://127.0.0.1:8080/examples/servlets/servlet/HelloServlet

This can be done because 127.0.0.1 is defined as the IP address of the local machine.

You will observe the output of the servlet in the browser display area. It will contain the string **Hello!** in bold type.

**The Servlet API**

Two packages contain the classes and interfaces that are required to build the servlets described in this chapter. These are `javax.servlet` and `javax.servlet.http`. They constitute the core of the Servlet API. Keep in mind that these packages are not part of the Java core packages. Therefore, they are not included with Java SE. Instead, they are provided by Tomcat. They are also provided by Java EE.

The Servlet API has been in a process of ongoing development and enhancement. The servlet specification supported by Tomcat 8.5.5 is version 3.1. (Subsequent versions of Tomcat are expected to support servlet specification 4.) This chapter discusses the core of the Servlet API, which will be available to most readers and works with all modern versions of the servlet specification.

**The `javax.servlet` Package**

The `javax.servlet` package contains a number of interfaces and classes that establish the framework in which servlets operate. The following table summarizes several key interfaces that are provided in this package. The most significant of these is `Servlet`. All servlets must implement this interface or extend a class that implements the interface. The `ServletRequest` and `ServletResponse` interfaces are also very important.
The following table summarizes the core classes that are provided in the `javax.servlet` package:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Servlet</td>
<td>Declares life cycle methods for a servlet.</td>
</tr>
<tr>
<td>ServletConfig</td>
<td>Allows servlets to get initialization parameters.</td>
</tr>
<tr>
<td>ServletContext</td>
<td>Enables servlets to log events and access information about their environment.</td>
</tr>
<tr>
<td>ServletRequest</td>
<td>Used to read data from a client request.</td>
</tr>
<tr>
<td>ServletResponse</td>
<td>Used to write data to a client response.</td>
</tr>
</tbody>
</table>

Let us examine these interfaces and classes in more detail.

**The Servlet Interface**

All servlets must implement the `Servlet` interface. It declares the `init()`, `service()`, and `destroy()` methods that are called by the server during the life cycle of a servlet. A method is also provided that allows a servlet to obtain any initialization parameters. The methods defined by `Servlet` are shown in Table 38-1.

The `init()`, `service()`, and `destroy()` methods are the life cycle methods of the servlet. These are invoked by the server. The `getServletConfig()` method is called by the servlet to obtain initialization parameters. A servlet developer overrides the `getServletInfo()` method to provide a string with useful information (for example, the version number). This method is also invoked by the server.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void destroy()</td>
<td>Called when the servlet is unloaded.</td>
</tr>
<tr>
<td>ServletConfig getServletConfig()</td>
<td>Returns a ServletConfig object that contains any initialization parameters.</td>
</tr>
<tr>
<td>String getServletInfo()</td>
<td>Returns a string describing the servlet.</td>
</tr>
<tr>
<td>void init(ServletConfig sc) throws ServletException</td>
<td>Called when the servlet is initialized. Initialization parameters for the servlet can be obtained from sc. A ServletException should be thrown if the servlet cannot be initialized.</td>
</tr>
<tr>
<td>void service(ServletRequest req, ServletResponse res) throws ServletException, IOException</td>
<td>Called to process a request from a client. The request from the client can be read from req. The response to the client can be written to res. An exception is generated if a servlet or IO problem occurs.</td>
</tr>
</tbody>
</table>

Table 38-1  The Methods Defined by Servlet

The ServletConfig Interface

The ServletConfig interface allows a servlet to obtain configuration data when it is loaded. The methods declared by this interface are summarized here:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ServletContext getServletContext()</td>
<td>Returns the context for this servlet.</td>
</tr>
<tr>
<td>String getInitParameter(String param)</td>
<td>Returns the value of the initialization parameter named param.</td>
</tr>
<tr>
<td>Enumeration&lt;String&gt; getInitParameterNames()</td>
<td>Returns an enumeration of all initialization parameter names.</td>
</tr>
<tr>
<td>String getServletName()</td>
<td>Returns the name of the invoking servlet.</td>
</tr>
</tbody>
</table>

The ServletContext Interface

The ServletContext interface enables servlets to obtain information about their environment. Several of its methods are summarized in Table 38-2.
Table 38-2 Various Methods Defined by ServletContext

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object getAttribute(String <em>attr</em>)</td>
<td>Returns the value of the server attribute named <em>attr</em>.</td>
</tr>
<tr>
<td>String getMimeType(String <em>file</em>)</td>
<td>Returns the MIME type of <em>file</em>.</td>
</tr>
<tr>
<td>String getRealPath(String <em>vpath</em>)</td>
<td>Returns the real (i.e., absolute) path that corresponds to the relative path <em>vpath</em>.</td>
</tr>
<tr>
<td>String getServerInfo()</td>
<td>Returns information about the server.</td>
</tr>
<tr>
<td>void log(String <em>s</em>)</td>
<td>Writes <em>s</em> to the servlet log.</td>
</tr>
<tr>
<td>void log(String <em>s</em>, Throwable <em>e</em>)</td>
<td>Writes <em>s</em> and the stack trace for <em>e</em> to the servlet log.</td>
</tr>
<tr>
<td>void setAttribute(String <em>attr</em>, Object <em>val</em>)</td>
<td>Sets the attribute specified by <em>attr</em> to the value passed in <em>val</em>.</td>
</tr>
</tbody>
</table>

The ServletRequest Interface

The ServletRequest interface enables a servlet to obtain information about a client request. Several of its methods are summarized in Table 38-3.
### Table 38-3 Various Methods Defined by ServletRequest

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>Object getAttribute(String attr)</code></td>
<td>Returns the value of the attribute named <code>attr</code>.</td>
</tr>
<tr>
<td><code>String getCharacterEncoding()</code></td>
<td>Returns the character encoding of the request.</td>
</tr>
<tr>
<td><code>int getContentType()</code></td>
<td>Returns the size of the request. The value -1 is returned if the size is unavailable.</td>
</tr>
<tr>
<td><code>String getContentType()</code></td>
<td>Returns the type of the request. A null value is returned if the type cannot be determined.</td>
</tr>
<tr>
<td><code>ServletInputStream getInputStream()</code></td>
<td>Returns a <code>ServletInputStream</code> that can be used to read binary data from the request. An <code>IllegalStateException</code> is thrown if <code>getReader()</code> has been previously invoked on this object.</td>
</tr>
<tr>
<td><code>String getParameter(String pname)</code></td>
<td>Returns the value of the parameter named <code>pname</code>.</td>
</tr>
<tr>
<td><code>Enumeration&lt;String&gt; getParameterNames()</code></td>
<td>Returns an enumeration of the parameter names for this request.</td>
</tr>
<tr>
<td><code>String[] getParameterValues(String name)</code></td>
<td>Returns an array containing values associated with the parameter specified by <code>name</code>.</td>
</tr>
<tr>
<td><code>String getProtocol()</code></td>
<td>Returns a description of the protocol.</td>
</tr>
<tr>
<td><code>BufferedReader getReader()</code></td>
<td>Returns a buffered reader that can be used to read text from the request. An <code>IllegalStateException</code> is thrown if <code>getInputStream()</code> has been previously invoked on this object.</td>
</tr>
<tr>
<td><code>String getRemoteAddr()</code></td>
<td>Returns the string equivalent of the client IP address.</td>
</tr>
<tr>
<td><code>String getRemoteHost()</code></td>
<td>Returns the string equivalent of the client host name.</td>
</tr>
<tr>
<td><code>String getScheme()</code></td>
<td>Returns the transmission scheme of the URL used for the request (for example, &quot;http&quot;, &quot;ftp&quot;).</td>
</tr>
<tr>
<td><code>String getServerName()</code></td>
<td>Returns the name of the server.</td>
</tr>
<tr>
<td><code>int getServerPort()</code></td>
<td>Returns the port number.</td>
</tr>
</tbody>
</table>

### The ServletResponse Interface

The `ServletResponse` interface enables a servlet to formulate a response for a client. Several of its methods are summarized in Table 38-4.
Table 38-4 Various Methods Defined by ServletResponse

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>String getCharacterEncoding( )</td>
<td>Returns the character encoding for the response.</td>
</tr>
<tr>
<td>ServletOutputStream getOutputStream( ) throws IOException</td>
<td>Returns a ServletOutputStream that can be used to write binary data to the response. An IllegalStateException is thrown if getWriter( ) has been previously invoked on this object.</td>
</tr>
<tr>
<td>PrintWriter getWriter( ) throws IOException</td>
<td>Returns a PrintWriter that can be used to write character data to the response. An IllegalStateException is thrown if getOutputStream( ) has been previously invoked on this object.</td>
</tr>
<tr>
<td>void setContentLength(int size)</td>
<td>Sets the content length for the response to size.</td>
</tr>
<tr>
<td>void setContentType(String type)</td>
<td>Sets the content type for the response to type.</td>
</tr>
</tbody>
</table>

The GenericServlet Class

The GenericServlet class provides implementations of the basic life cycle methods for a servlet. GenericServlet implements the Servlet and ServletConfig interfaces. In addition, a method to append a string to the server log file is available. The signatures of this method are shown here:

  void log(String s)
  void log(String s, Throwable e)

Here, s is the string to be appended to the log, and e is an exception that occurred.

The ServletInputStream Class

The ServletInputStream class extends InputStream. It is implemented by the servlet container and provides an input stream that a servlet developer can use to read the data from a client request. In addition to the input methods inherited from InputStream, a method is provided to read bytes from the stream. It is shown here:

  int readLine(byte[ ] buffer, int offset, int size) throws IOException

Here, buffer is the array into which size bytes are placed starting at offset. The method returns the actual number of bytes read or −1 if an end-of-stream condition is encountered.

The ServletOutputStream Class
The `ServletOutputStream` class extends `OutputStream`. It is implemented by the servlet container and provides an output stream that a servlet developer can use to write data to a client response. In addition to the output methods provided by `OutputStream`, it also defines the `print()` and `println()` methods, which output data to the stream.

**The Servlet Exception Classes**

`javax.servlet` defines two exceptions. The first is `ServletException`, which indicates that a servlet problem has occurred. The second is `UnavailableException`, which extends `ServletException`. It indicates that a servlet is unavailable.

**Reading Servlet Parameters**

The `ServletRequest` interface includes methods that allow you to read the names and values of parameters that are included in a client request. We will develop a servlet that illustrates their use. The example contains two files. A web page is defined in `PostParameters.html`, and a servlet is defined in `PostParametersServlet.java`.

The HTML source code for `PostParameters.html` is shown in the following listing. It defines a table that contains two labels and two text fields. One of the labels is Employee and the other is Phone. There is also a submit button. Notice that the action parameter of the form tag specifies a URL. The URL identifies the servlet to process the HTTP POST request.
The source code for PostParametersServlet.java is shown in the following listing. The service() method is overridden to process client requests. The getParameterNames() method returns an enumeration of the parameter names. These are processed in a loop. You can see that the parameter name and value are output to the client. The parameter value is obtained via the getParameter() method.
import java.io.*;
import java.util.*;
import javax.servlet.*;

public class PostParametersServlet 
extends GenericServlet {

    public void service(ServletRequest request, 
            ServletResponse response) 
    throws ServletException, IOException {

        // Get print writer.
        PrintWriter pw = response.getWriter();

        // Get enumeration of parameter names.
        Enumeration<String> e = request.getParameterNames();

        // Display parameter names and values.
        while(e.hasMoreElements()) {
            String pname = e.nextElement();
            pw.print(pname + " = ");
            String pvalue = request.getParameter(pname);
            pw.println(pvalue);
        }
        pw.close();
    }
}

Compile the servlet. Next, copy it to the appropriate directory, and update the 
web.xml file, as previously described. Then, perform these steps to test this example:

1. Start Tomcat (if it is not already running).
2. Display the web page in a browser.
3. Enter an employee name and phone number in the text fields.
4. Submit the web page.

After following these steps, the browser will display a response that is dynamically 
generated by the servlet.

The javax.servlet.http Package

The preceding examples have used the classes and interfaces defined in
javax.servlet, such as ServletRequest, ServletResponse, and GenericServlet, to illustrate the basic functionality of servlets. However, when working with HTTP, you will normally use the interfaces and classes in javax.servlet.http. As you will see, its functionality makes it easy to build servlets that work with HTTP requests and responses.

The following table summarizes the interfaces used in this chapter:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HttpServletRequest</td>
<td>Enables servlets to read data from an HTTP request.</td>
</tr>
<tr>
<td>HttpServletResponse</td>
<td>Enables servlets to write data to an HTTP response.</td>
</tr>
<tr>
<td>HttpSession</td>
<td>Allows session data to be read and written.</td>
</tr>
</tbody>
</table>

The following table summarizes the classes used in this chapter. The most important of these is HttpServlet. Servlet developers typically extend this class in order to process HTTP requests.

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cookie</td>
<td>Allows state information to be stored on a client machine.</td>
</tr>
<tr>
<td>HttpServlet</td>
<td>Provides methods to handle HTTP requests and responses.</td>
</tr>
</tbody>
</table>

The HttpServletRequest Interface

The HttpServletRequest interface enables a servlet to obtain information about a client request. Several of its methods are shown in Table 38-5.

The HttpServletResponse Interface

The HttpServletResponse interface enables a servlet to formulate an HTTP response to a client. Several constants are defined. These correspond to the different status codes that can be assigned to an HTTP response. For example, SC_OK indicates that the HTTP request succeeded, and SC_NOT_FOUND indicates that the requested resource is not available. Several methods of this interface are summarized in Table 38-6.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>String getAuthType()</td>
<td>Returns authentication scheme.</td>
</tr>
<tr>
<td>Cookie[] getCookies()</td>
<td>Returns an array of the cookies in this request.</td>
</tr>
<tr>
<td>long getDateHeader(String field)</td>
<td>Returns the value of the date header field named field.</td>
</tr>
<tr>
<td>String getHeader(String field)</td>
<td>Returns the value of the header field named field.</td>
</tr>
<tr>
<td>Enumeration&lt;String&gt; getHeaderNames()</td>
<td>Returns an enumeration of the header names.</td>
</tr>
<tr>
<td>int getIntHeader(String field)</td>
<td>Returns the int equivalent of the header field named field.</td>
</tr>
<tr>
<td>String getMethod()</td>
<td>Returns the HTTP method for this request.</td>
</tr>
<tr>
<td>String getPathInfo()</td>
<td>Returns any path information that is located after the servlet path and before a query string of the URL.</td>
</tr>
<tr>
<td>String getPathTranslated()</td>
<td>Returns any path information that is located after the servlet path and before a query string of the URL after translating it to a real path.</td>
</tr>
<tr>
<td>String getQueryString()</td>
<td>Returns any query string in the URL.</td>
</tr>
<tr>
<td>String getRemoteUser()</td>
<td>Returns the name of the user who issued this request.</td>
</tr>
<tr>
<td>String getRequestedSessionId()</td>
<td>Returns the ID of the session.</td>
</tr>
<tr>
<td>String getRequestURI()</td>
<td>Returns the URI.</td>
</tr>
<tr>
<td>StringBuffer getRequestURL()</td>
<td>Returns the URL.</td>
</tr>
<tr>
<td>String getServletPath()</td>
<td>Returns that part of the URL that identifies the servlet.</td>
</tr>
<tr>
<td>HttpSession getSession()</td>
<td>Returns the session for this request. If a session does not exist, one is created and then returned.</td>
</tr>
<tr>
<td>HttpSession getSession(boolean new)</td>
<td>If new is true and no session exists, creates and returns a session for this request. Otherwise, returns the existing session for this request.</td>
</tr>
<tr>
<td>boolean isRequestedSessionIdFromCookie()</td>
<td>Returns true if a cookie contains the session ID. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean isRequestedSessionIdFromURL()</td>
<td>Returns true if the URL contains the session ID. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean isRequestedSessionIdValid()</td>
<td>Returns true if the requested session ID is valid in the current session context.</td>
</tr>
</tbody>
</table>

Table 38-5 Various Methods Defined by HttpServletRequest
The HttpSession Interface

The HttpSession interface enables a servlet to read and write the state information that is associated with an HTTP session. Several of its methods are summarized in Table 38-7. All of these methods throw an IllegalStateException if the session has already been invalidated.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void addCookie(Cookie cookie)</td>
<td>Adds cookie to the HTTP response.</td>
</tr>
<tr>
<td>boolean containsHeader(String field)</td>
<td>Returns true if the HTTP response header contains a field named field.</td>
</tr>
<tr>
<td>String encodeURL(String url)</td>
<td>Determines if the session ID must be encoded in the URL identified as url. If so, returns the modified version of url. Otherwise, returns url. All URLs generated by a servlet should be processed by this method.</td>
</tr>
<tr>
<td>String encodeRedirectURL(String url)</td>
<td>Determines if the session ID must be encoded in the URL identified as url. If so, returns the modified version of url. Otherwise, returns url. All URLs passed to sendRedirect() should be processed by this method.</td>
</tr>
<tr>
<td>void sendError(int c) throws IOException</td>
<td>Sends the error code c to the client.</td>
</tr>
<tr>
<td>void sendError(int c, String s) throws IOException</td>
<td>Sends the error code c and message s to the client.</td>
</tr>
<tr>
<td>void sendRedirect(String url) throws IOException</td>
<td>Redirects the client to url.</td>
</tr>
<tr>
<td>void setDateHeader(String field, long msec)</td>
<td>Adds field to the header with date value equal to msec (milliseconds since midnight, January 1, 1970, GMT).</td>
</tr>
<tr>
<td>void setHeader(String field, String value)</td>
<td>Adds field to the header with value equal to value.</td>
</tr>
<tr>
<td>void setIntHeader(String field, int value)</td>
<td>Adds field to the header with value equal to value.</td>
</tr>
<tr>
<td>void setStatus(int code)</td>
<td>Sets the status code for this response to code.</td>
</tr>
</tbody>
</table>

Table 38-6 Various Methods Defined by HttpServletResponse

The Cookie Class
The **Cookie** class encapsulates a cookie. A *cookie* is stored on a client and contains state information. Cookies are valuable for tracking user activities. For example, assume that a user visits an online store. A cookie can save the user’s name, address, and other information. The user does not need to enter this data each time he or she visits the store.

A servlet can write a cookie to a user’s machine via the **addCookie()** method of the **HttpServletResponse** interface. The data for that cookie is then included in the header of the HTTP response that is sent to the browser.

The names and values of cookies are stored on the user’s machine. Some of the information that can be saved for each cookie includes the following:

- The name of the cookie
- The value of the cookie
- The expiration date of the cookie
- The domain and path of the cookie

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object.getAttribute(String <em>attr</em>)</td>
<td>Returns the value associated with the name passed in <em>attr</em>. Returns <strong>null</strong> if <em>attr</em> is not found.</td>
</tr>
<tr>
<td>Enumeration&lt;String&gt; . . . getAttributeNames()</td>
<td>Returns an enumeration of the attribute names associated with the session.</td>
</tr>
<tr>
<td>long getCreationTime()</td>
<td>Returns the creation time (in milliseconds since midnight, January 1, 1970, GMT) of the invoking session.</td>
</tr>
<tr>
<td>String getId()</td>
<td>Returns the session ID.</td>
</tr>
<tr>
<td>long getLast AccessedTime()</td>
<td>Returns the time (in milliseconds since midnight, January 1, 1970, GMT) when the client last made a request on the invoking session.</td>
</tr>
<tr>
<td>void invalidate()</td>
<td>Invalidates this session and removes it from the context.</td>
</tr>
<tr>
<td>boolean isNew()</td>
<td>Returns <strong>true</strong> if the server created the session and it has not yet been accessed by the client.</td>
</tr>
<tr>
<td>void removeAttribute(String <em>attr</em>)</td>
<td>Removes the attribute specified by <em>attr</em> from the session.</td>
</tr>
<tr>
<td>void setAttribute(String <em>attr</em>, Object <em>val</em>)</td>
<td>Associates the value passed in <em>val</em> with the attribute name passed in <em>attr</em>.</td>
</tr>
</tbody>
</table>

**Table 38-7** Various Methods Defined by **HttpSession**
The expiration date determines when this cookie is deleted from the user’s machine. If an expiration date is not explicitly assigned to a cookie, it is deleted when the current browser session ends.

The domain and path of the cookie determine when it is included in the header of an HTTP request. If the user enters a URL whose domain and path match these values, the cookie is then supplied to the web server. Otherwise, it is not.

There is one constructor for `Cookie`. It has the signature shown here:

```java
Cookie(String name, String value)
```

Here, the name and value of the cookie are supplied as arguments to the constructor.

The methods of the `Cookie` class are summarized in Table 38-8.

---

**The HttpServlet Class**

The `HttpServlet` class extends `GenericServlet`. It is commonly used when developing servlets that receive and process HTTP requests. The methods defined by the `HttpServlet` class are summarized in Table 38-9.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>Object clone()</code></td>
<td>Returns a copy of this object.</td>
</tr>
<tr>
<td><code>String getComment()</code></td>
<td>Returns the comment.</td>
</tr>
<tr>
<td><code>String getDomain()</code></td>
<td>Returns the domain.</td>
</tr>
<tr>
<td><code>int getMaxAge()</code></td>
<td>Returns the maximum age (in seconds).</td>
</tr>
<tr>
<td><code>String getName()</code></td>
<td>Returns the name.</td>
</tr>
<tr>
<td><code>String getPath()</code></td>
<td>Returns the path.</td>
</tr>
<tr>
<td><code>boolean getSecure()</code></td>
<td>Returns <code>true</code> if the cookie is secure. Otherwise, returns <code>false</code>.</td>
</tr>
<tr>
<td><code>String getValue()</code></td>
<td>Returns the value.</td>
</tr>
<tr>
<td><code>int getVersion()</code></td>
<td>Returns the version.</td>
</tr>
<tr>
<td><code>boolean isHttpOnly()</code></td>
<td>Returns <code>true</code> if the cookie has the <code>HttpOnly</code> attribute.</td>
</tr>
<tr>
<td><code>void setComment(String c)</code></td>
<td>Sets the comment to <code>c</code></td>
</tr>
<tr>
<td><code>void setDomain(String d)</code></td>
<td>Sets the domain to <code>d</code>.</td>
</tr>
<tr>
<td><code>void setHttpOnly(boolean httpOnly)</code></td>
<td>If <code>httpOnly</code> is <code>true</code>, then the <code>HttpOnly</code> attribute is added to the cookie. If <code>httpOnly</code> is <code>false</code>, the <code>HttpOnly</code> attribute is removed.</td>
</tr>
<tr>
<td><code>void setMaxAge(int secs)</code></td>
<td>Sets the maximum age of the cookie to <code>secs</code>. This is the number of seconds after which the cookie is deleted.</td>
</tr>
<tr>
<td><code>void setPath(String p)</code></td>
<td>Sets the path to <code>p</code>.</td>
</tr>
<tr>
<td><code>void setSecure(boolean secure)</code></td>
<td>Sets the security flag to <code>secure</code>.</td>
</tr>
<tr>
<td><code>void setValue(String v)</code></td>
<td>Sets the value to <code>v</code>.</td>
</tr>
<tr>
<td><code>void setVersion(int v)</code></td>
<td>Sets the version to <code>v</code>.</td>
</tr>
</tbody>
</table>

**Table 38-8** The Methods Defined by **Cookie**
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void doDelete(HttpServletRequest req, HttpServletResponse res) throws IOException, ServletException</td>
<td>Handles an HTTP DELETE request.</td>
</tr>
<tr>
<td>void doGet(HttpServletRequest req, HttpServletResponse res) throws IOException, ServletException</td>
<td>Handles an HTTP GET request.</td>
</tr>
<tr>
<td>void doHead(HttpServletRequest req, HttpServletResponse res) throws IOException, ServletException</td>
<td>Handles an HTTP HEAD request.</td>
</tr>
<tr>
<td>void doOptions(HttpServletRequest req, HttpServletResponse res) throws IOException, ServletException</td>
<td>Handles an HTTP OPTIONS request.</td>
</tr>
<tr>
<td>void doPost(HttpServletRequest req, HttpServletResponse res) throws IOException, ServletException</td>
<td>Handles an HTTP POST request.</td>
</tr>
<tr>
<td>void doPut(HttpServletRequest req, HttpServletResponse res) throws IOException, ServletException</td>
<td>Handles an HTTP PUT request.</td>
</tr>
<tr>
<td>void doTrace(HttpServletRequest req, HttpServletResponse res) throws IOException, ServletException</td>
<td>Handles an HTTP TRACE request.</td>
</tr>
<tr>
<td>long getLastModified(HttpServletRequest req)</td>
<td>Returns the time (in milliseconds since midnight, January 1, 1970, GMT) when the requested resource was last modified.</td>
</tr>
<tr>
<td>void service(HttpServletRequest req, HttpServletResponse res) throws IOException, ServletException</td>
<td>Called by the server when an HTTP request arrives for this servlet. The arguments provide access to the HTTP request and response, respectively.</td>
</tr>
</tbody>
</table>

Table 38-9  The Methods Defined by HttpServlet

Handling HTTP Requests and Responses

The HttpServlet class provides specialized methods that handle the various types of HTTP requests. A servlet developer typically overrides one of these methods. These methods are doDelete(), doGet(), doHead(), doOptions(), doPost(), doPut(),
and `doTrace()`. A complete description of the different types of HTTP requests is beyond the scope of this book. However, the GET and POST requests are commonly used when handling form input. Therefore, this section presents examples of these cases.

### Handling HTTP GET Requests

Here we will develop a servlet that handles an HTTP GET request. The servlet is invoked when a form on a web page is submitted. The example contains two files. A web page is defined in `ColorGet.html`, and a servlet is defined in `ColorGetServlet.java`. The HTML source code for `ColorGet.html` is shown in the following listing. It defines a form that contains a select element and a submit button. Notice that the action parameter of the form tag specifies a URL. The URL identifies a servlet to process the HTTP GET request.

```html
<html>
<body>
<center>
<form name="Form1"
    action="http://localhost:8080/examples/servlets/servlet/ColorGetServlet">
    <B>Color:</B>
    <select name="color" size="1">
        <option value="Red">Red</option>
        <option value="Green">Green</option>
        <option value="Blue">Blue</option>
    </select>
    <br><br>
    <input type="submit" value="Submit">
</form>
</body>
</html>
```

The source code for `ColorGetServlet.java` is shown in the following listing. The `doGet()` method is overridden to process any HTTP GET requests that are sent to this servlet. It uses the `getParameter()` method of `HttpServletRequest` to obtain the selection that was made by the user. A response is then formulated.
Compile the servlet. Next, copy it to the appropriate directory, and update the web.xml file, as previously described. Then, perform these steps to test this example:

1. Start Tomcat, if it is not already running.
2. Display the web page in a browser.
3. Select a color.
4. Submit the web page.

After completing these steps, the browser will display the response that is dynamically generated by the servlet.

One other point: Parameters for an HTTP GET request are included as part of the URL that is sent to the web server. Assume that the user selects the red option and submits the form. The URL sent from the browser to the server is


The characters to the right of the question mark are known as the **query string**.

**Handling HTTP POST Requests**

Here we will develop a servlet that handles an HTTP POST request. The servlet is invoked when a form on a web page is submitted. The example contains two files. A web page is defined in **ColorPost.html**, and a servlet is defined in
The HTML source code for **ColorPost.html** is shown in the following listing. It is identical to **ColorGet.html** except that the method parameter for the form tag explicitly specifies that the POST method should be used, and the action parameter for the form tag specifies a different servlet.

```html
<html>
<body>
<center>
<form name="Form1"
     method="post"
     action="http://localhost:8080/examples/servlets/servlet/ColorPostServlet">
   <B>Color:</B>
   <select name="color" size="1">
      <option value="Red">Red</option>
      <option value="Green">Green</option>
      <option value="Blue">Blue</option>
   </select>
   <br><br>
   <input type="submit" value="Submit">
</form>
</body>
</html>
```

The source code for **ColorPostServlet.java** is shown in the following listing. The **doPost()** method is overridden to process any HTTP POST requests that are sent to this servlet. It uses the **getParameter()** method of **HttpServletRequest** to obtain the selection that was made by the user. A response is then formulated.
Compile the servlet and perform the same steps as described in the previous section to test it.

**NOTE** Parameters for an HTTP POST request are not included as part of the URL that is sent to the web server. In this example, the URL sent from the browser to the server is


The parameter names and values are sent in the body of the HTTP request.

### Using Cookies

Now, let’s develop a servlet that illustrates how to use cookies. The servlet is invoked when a form on a web page is submitted. The example contains three files as summarized here:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AddCookie.html</td>
<td>Allows a user to specify a value for the cookie named MyCookie.</td>
</tr>
<tr>
<td>AddCookieServlet.java</td>
<td>Processes the submission of AddCookie.html.</td>
</tr>
<tr>
<td>GetCookiesServlet.java</td>
<td>Displays cookie values.</td>
</tr>
</tbody>
</table>

The HTML source code for AddCookie.html is shown in the following listing. This page contains a text field in which a value can be entered. There is also a submit
button on the page. When this button is pressed, the value in the text field is sent to
**AddCookieServlet** via an HTTP POST request.

```html
<html>
<body>
<center>
<form name="Form1"
    method="post"
    action="http://localhost:8080/examples/servlets/servlet/AddCookieServlet">
    <B>Enter a value for MyCookie:</B>
    <input type=textbox name="data" size=25 value=""/>
    <input type=submit value="Submit"/>
</form>
</body>
</html>
```

The source code for **AddCookieServlet.java** is shown in the following listing. It gets the value of the parameter named "data". It then creates a **Cookie** object that has the name "MyCookie" and contains the value of the "data" parameter. The cookie is then added to the header of the HTTP response via the **addCookie( )** method. A feedback message is then written to the browser.
import java.io.*;
import javax.servlet.*;
import javax.servlet.http.*;

public class AddCookieServlet extends HttpServlet {

    public void doPost(HttpServletRequest request, 
                        HttpServletResponse response) 
        throws ServletException, IOException {

        // Get parameter from HTTP request.
        String data = request.getParameter("data");

        // Create cookie.
        Cookie cookie = new Cookie("MyCookie", data);

        // Add cookie to HTTP response.
        response.addCookie(cookie);

        // Write output to browser.
        response.setContentType("text/html");  
        PrintWriter pw = response.getWriter();
        pw.println("<B>MyCookie has been set to");  
        pw.println(data);
        pw.close();
    }
}

The source code for GetCookiesServlet.java is shown in the following listing. It invokes the getCookie() method to read any cookies that are included in the HTTP GET request. The names and values of these cookies are then written to the HTTP response. Observe that the getName() and getValue() methods are called to obtain this information.
import java.io.*;
import javax.servlet.*;
import javax.servlet.http.*;

public class GetCookiesServlet extends HttpServlet {

    public void doGet(HttpServletRequest request, HttpServletResponse response)
        throws ServletException, IOException {

        // Get cookies from header of HTTP request.
        Cookie[] cookies = request.getCookies();

        // Display these cookies.
        response.setContentType("text/html");
        PrintWriter pw = response.getWriter();
        pw.println("<B>");
        for(int i = 0; i < cookies.length; i++) {
            String name = cookies[i].getName();
            String value = cookies[i].getValue();
            pw.println("name = " + name + " ; value = " + value);
        }
        pw.close();
    }
}

Compile the servlets. Next, copy them to the appropriate directory, and update the web.xml file, as previously described. Then, perform these steps to test this example:

1. Start Tomcat, if it is not already running.
2. Display AddCookie.html in a browser.
3. Enter a value for MyCookie.
4. Submit the web page.

After completing these steps, you will observe that a feedback message is displayed by the browser.

Next, request the following URL via the browser:

http://localhost:8080/examples/servlets/servlet/GetCookiesServlet

Observe that the name and value of the cookie are displayed in the browser.

In this example, an expiration date is not explicitly assigned to the cookie via the
setMaxAge( ) method of Cookie. Therefore, the cookie expires when the browser session ends. You can experiment by using `setMaxAge( )` and observe that the cookie is then saved on the client machine.

**Session Tracking**

HTTP is a stateless protocol. Each request is independent of the previous one. However, in some applications, it is necessary to save state information so that information can be collected from several interactions between a browser and a server. Sessions provide such a mechanism.

A session can be created via the `getSession( )` method of `HttpServletRequest`. An `HttpSession` object is returned. This object can store a set of bindings that associate names with objects. The `setAttribute( )`, `getAttribute( )`, `getAttributeNames( )`, and `removeAttribute( )` methods of `HttpSession` manage these bindings. Session state is shared by all servlets that are associated with a client.

The following servlet illustrates how to use session state. The `getSession( )` method gets the current session. A new session is created if one does not already exist. The `getAttribute( )` method is called to obtain the object that is bound to the name "date". That object is a `Date` object that encapsulates the date and time when this page was last accessed. (Of course, there is no such binding when the page is first accessed.) A `Date` object encapsulating the current date and time is then created. The `setAttribute( )` method is called to bind the name "date" to this object.

```java
import java.io.*;
import java.util.*;
import javax.servlet.*;
import javax.servlet.http.*;

public class DateServlet extends HttpServlet {
```
When you first request this servlet, the browser displays one line with the current date and time information. On subsequent invocations, two lines are displayed. The first line shows the date and time when the servlet was last accessed. The second line shows the current date and time.
PART
VI Appendixes

APPENDIX A
Using Java’s Documentation Comments

APPENDIX B
An Overview of Java Web Start

APPENDIX C
Introducing JShell

APPENDIX D
Applet Basics
A Using Java’s Documentation Comments

As explained in Part I, Java supports three types of comments. The first two are the // and the /* */. The third type is called a documentation comment. It begins with the character sequence /**. It ends with */. Documentation comments allow you to embed information about your program into the program itself. You can then use the javadoc utility program (supplied with the JDK) to extract the information and put it into an HTML file. Documentation comments make it convenient to document your programs. You have almost certainly seen documentation that uses such comments because that is the way the Java API library was documented. Beginning with JDK 9, javadoc includes support for modules.

The javadoc Tags

The javadoc utility recognizes several tags, including those shown here:

<table>
<thead>
<tr>
<th>Tag</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>@author</td>
<td>Identifies the author.</td>
</tr>
<tr>
<td>{@code}</td>
<td>Displays information as-is, without processing HTML styles, in code font.</td>
</tr>
<tr>
<td>@deprecated</td>
<td>Specifies that a program element is deprecated.</td>
</tr>
<tr>
<td>{@docRoot}</td>
<td>Specifies the path to the root directory of the current documentation.</td>
</tr>
<tr>
<td>@exception</td>
<td>Identifies an exception thrown by a method or constructor.</td>
</tr>
<tr>
<td>@hidden</td>
<td>Prevents an element from appearing in the documentation. (Added by JDK 9.)</td>
</tr>
<tr>
<td>{@index}</td>
<td>Specifies a term for indexing. (Added by JDK 9.)</td>
</tr>
<tr>
<td>@inheritDoc</td>
<td>Inherits a comment from the immediate superclass.</td>
</tr>
<tr>
<td>@link</td>
<td>Inserts an in-line link to another topic.</td>
</tr>
<tr>
<td>@linkplain</td>
<td>Inserts an in-line link to another topic, but the link is displayed in a plain-text font.</td>
</tr>
<tr>
<td>{@literal}</td>
<td>Displays information as-is, without processing HTML styles.</td>
</tr>
<tr>
<td>@param</td>
<td>Documents a parameter.</td>
</tr>
</tbody>
</table>
Document tags that begin with an “at” sign (@) are called stand-alone tags (also called block tags), and they must be used on their own line. Tags that begin with a brace, such as {@code}, are called in-line tags, and they can be used within a larger description. You may also use other, standard HTML tags in a documentation comment. However, some tags, such as headings, should not be used because they disrupt the look of the HTML file produced by javadoc.

As it relates to documenting source code, you can use documentation comments to document classes, interfaces, fields, constructors, methods, and modules. In all cases, the documentation comment must immediately precede the item being documented. Some tags, such as @see, @since, and @deprecated, can be used to document any element. Other tags apply only to the relevant elements. Each tag is examined next.

NOTE Documentation comments can also be used for documenting a package and preparing an overview, but the procedures differ from those used to document source code. See the javadoc documentation for details on these uses. Beginning with JDK 9, javadoc can also document a module-info.java file.

@author

The @author tag documents the author of a program element. It has the following syntax:

    @author description
Here, \textit{description} will usually be the name of the author. You will need to specify the \texttt{-author} option when executing \texttt{javadoc} in order for the \texttt{@author} field to be included in the HTML documentation.

\texttt{@code}

The \texttt{@code} tag enables you to embed text, such as a snippet of code, into a comment. That text is then displayed as-is in code font, without any further processing, such as HTML rendering. It has the following syntax:

\texttt{@code code-snippet}

\texttt{@deprecated}

The \texttt{@deprecated} tag specifies that a program element is deprecated. It is recommended that you include \texttt{@see} or \texttt{@link} tags to inform the programmer about available alternatives. The syntax is the following:

\texttt{@deprecated description}

Here, \textit{description} is the message that describes the deprecation. The \texttt{@deprecated} tag can be used in documentation for fields, methods, constructors, classes, and interfaces.

\texttt{@docRoot}

\texttt{@docRoot} specifies the path to the root directory of the current documentation.

\texttt{@exception}

The \texttt{@exception} tag describes an exception to a method. It has the following syntax:

\texttt{@exception exception-name explanation}

Here, the fully qualified name of the exception is specified by \textit{exception-name}, and \textit{explanation} is a string that describes how the exception can occur. The \texttt{@exception} tag can only be used in documentation for a method or constructor.

\texttt{@hidden}

The \texttt{@hidden} tag prevents an element from appearing in the documentation. This tag was added by JDK 9.
The `@index` tag specifies an item that will be indexed, and thus found when using the search feature added by JDK 9. It has the following syntax:

```java
@index term usage-str
```

Here, `term` is the item (which can be a quoted string) to be indexed. `usage-str` is optional. Thus, in the following `@exception` tag, `@index` causes the term “error” to be added to the index:

```java
@exception IOException On input @index error.
```

Note that the word “error” is still displayed as part of the description. It’s just that now it is also indexed. If you include the optional `usage-str`, then that description will be shown in the index and in the search box to indicate how the term is used. For example, `@index error Serious execution failure` will show “Serious execution failure” under “error” in the index and in the search box. This tag was added by JDK 9.

The `@inheritDoc` tag inherits a comment from the immediate superclass.

The `@link` tag provides an in-line link to additional information. It has the following syntax:

```java
@link pkg.class#member text
```

Here, `pkg.class#member` specifies the name of a class or method to which a link is added, and `text` is the string that is displayed.

The `@linkplain` tag inserts an in-line link to another topic. The link is displayed in plain-text font. Otherwise, it is similar to `@link`.

The `@literal` tag enables you to embed text into a comment. That text is then
displayed as-is, without any further processing, such as HTML rendering. It has the following syntax:

{@literal description}

Here, *description* is the text that is embedded.

**@param**
The **@param** tag documents a parameter. It has the following syntax:

@param parameter-name explanation

Here, *parameter-name* specifies the name of a parameter. The meaning of that parameter is described by *explanation*. The **@param** tag can be used only in documentation for a method or constructor, or a generic class or interface.

**@provides**
The **@provides** tag documents a service provided by a module. It has the following syntax:

@provides type explanation

Here, *type* specifies a service provider type and *explanation* describes the service provider. This tag was added by JDK 9.

**@return**
The **@return** tag describes the return value of a method. It has the following syntax:

@return explanation

Here, *explanation* describes the type and meaning of the value returned by a method. The **@return** tag can be used only in documentation for a method.

**@see**
The **@see** tag provides a reference to additional information. Two commonly used forms are shown here:

@see anchor
@see pkg.class#member text
In the first form, *anchor* is a link to an absolute or relative URL. In the second form, *pkg.class#member* specifies the name of the item, and *text* is the text displayed for that item. The text parameter is optional, and if not used, then the item specified by *pkg.class#member* is displayed. The member name, too, is optional. Thus, you can specify a reference to a package, class, or interface in addition to a reference to a specific method or field. The name can be fully qualified or partially qualified. However, the dot that precedes the member name (if it exists) must be replaced by a hash character.

**@serial**

The *@serial* tag defines the comment for a default serializable field. It has the following syntax:

    @serial description

Here, *description* is the comment for that field.

**@serialData**

The *@serialData* tag documents the data written by the *writeObject( )* and *writeExternal( )* methods. It has the following syntax:

    @serialData description

Here, *description* is the comment for that data.

**@serialField**

For a class that implements *Serializable*, the *@serialField* tag provides comments for an *ObjectStreamField* component. It has the following syntax:

    @serialField name type description

Here, *name* is the name of the field, *type* is its type, and *description* is the comment for that field.

**@since**

The *@since* tag states that an element was introduced in a specific release. It has the following syntax:
Here, release is a string that designates the release or version in which this feature became available.

@throws
The @throws tag has the same meaning as the @exception tag.

@uses
The @uses tag documents a service provider needed by a module. It has the following syntax:

    @uses type explanation

Here, type specifies a service provider type and explanation describes the service. This tag was added by JDK 9.

{@value}
{@value} has two forms. The first displays the value of the constant that it precedes, which must be a static field. It has this form:

    {@value}

The second form displays the value of a specified static field. It has this form:

    {@value pkg.class#field}

Here, pkg.class#field specifies the name of the static field.

@version
The @version tag specifies the version of a program element. It has the following syntax:

    @version info

Here, info is a string that contains version information, typically a version number, such as 2.2. You will need to specify the -version option when executing javadoc in order for the @version field to be included in the HTML documentation.
The General Form of a Documentation Comment

After the beginning /***, the first line or lines become the main description of your class, interface, field, constructor, method, or module. After that, you can include one or more of the various @ tags. Each @ tag must start at the beginning of a new line or follow one or more asterisks (*) that are at the start of a line. Multiple tags of the same type should be grouped together. For example, if you have three @see tags, put them one after the other. In-line tags (those that begin with a brace) can be used within any description.

Here is an example of a documentation comment for a class:

```java
/**
 * This class draws a bar chart.
 * @author Herbert Schildt
 * @version 3.2
 */
```

What javadoc Outputs

The javadoc program takes as input your Java program’s source file and outputs several HTML files that contain the program’s documentation. Information about each class will be in its own HTML file. javadoc will also output an index and a hierarchy tree. Other HTML files can be generated. Beginning with JDK 9, a search box feature is also included.

An Example that Uses Documentation Comments

Following is a sample program that uses documentation comments. Notice the way each comment immediately precedes the item that it describes. After being processed by javadoc, the documentation about the SquareNum class will be found in SquareNum.html.
import java.io.*;
/**
 * This class demonstrates documentation comments.
 * @author Herbert Schildt
 * @version 1.2
 */
public class SquareNum {

    /**
     * This method returns the square of num.
     * This is a multiline description. You can use
     * as many lines as you like.
     * @param num The value to be squared.
     * @return num squared.
     */
    public double square(double num) {
        return num * num;
    }

    /**
     * This method inputs a number from the user.
     * @return The value input as a double.
     * @exception IOException On input error.
     * @see IOException
     */
    public double getNumber() throws IOException {
        // create a BufferedReader using System.in
        InputStreamReader isr = new InputStreamReader(System.in);
        BufferedReader inData = new BufferedReader(isr);
        String str;

        str = inData.readLine();
        return (new Double(str)).doubleValue();
    }

    /**
     * This method demonstrates square().
     * @param args Unused.
     * @exception IOException On input error.
     * @see IOException
     */
public static void main(String args[])
    throws IOException
{
    SquareNum ob = new SquareNum();
    double val;

    System.out.println("Enter value to be squared: ");
    val = ob.getNumber();
    val = ob.square(val);

    System.out.println("Squared value is " + val);
}
}
APPENDIX
B An Overview of Java Web Start

As mentioned in Chapter 1, with the release of JDK 9 applets are no longer recommended for the development of web-based applications. Although applets served Java well for many years, they rely on a browser plug-in, and support for the Java browser plug-in has been eroding. For this and other reasons, the use of Java Web Start is now recommended for the deployment of web-based programs. The key advantage of Java Web Start is that no browser plug-in is required. Thus, an application deployed via Java Web Start can run independently of the browser.

It is important to state at the outset that the subject of Java Web Start, and deployment strategies in general, is quite large. Furthermore, Java Web Start relies on many other deployment-related features, such as JAR files, manifest files, application signing, and JNLP files. Additionally, there are several other considerations relating to the deployment of commercial applications. Normally, a discussion of deployment would be outside the scope of this book. However, because of the increased importance of Java Web Start, a brief discussion that introduces several of its key aspects is included here. The goal is to give you a general sense of how Java Web Start works. As you advance in your Java programming career, you will want to study Java Web Start in detail.

NOTE Because deployment of Java applications is subject to change and/or enhancement, especially as it relates to security issues, it is strongly recommended that you consult the Oracle documentation pertaining to deployment for the latest information. Also, the following discussion assumes an environment that supports a modern version of Java.

What Is Java Web Start?

At its core, Java Web Start is a mechanism that supports the web-based deployment of Java applications. Unlike a Java applet, which must extend either the Applet or JApplet class and support the general applet architecture by supplying the init(), start(), stop(), and destroy() methods, Java Web Start applications are “normal,” client-based programs, such as those shown in the Swing and JavaFX chapters of this book. In other words, a Java Web Start application is essentially a rich client application that is downloaded and executed from the Web. For example, a program
such as **JListDemo** in the Swing chapter can be run as a Java Web Start application with no changes whatsoever.

Because Java Web Start does not use a browser plug-in, a Java Web Start application requires that only the JRE be installed on the host computer. This eliminates the problem with missing, disabled, or out-of-date plug-ins. Because the Java Web Start application runs on the desktop (not within the browser), your program will look and feel like a “normal” application on the host. Furthermore, once a Java Web Start application has been downloaded, it is possible to execute it offline. It is also possible to create a shortcut to the application. Frankly, Java Web Start offers the application developer the ability to create applications whose functionality exceeds what would have normally been appropriate or feasible for an applet.

By default, Java Web Start applications run in the same security “sandbox” used by unsigned applets, and thus have the same restrictions. So by default, Java Web Start applications provide security protections similar to that of unsigned applets. It is possible, however, to give a Java Web Start application additional security permissions, if required.

**Four Key Java Web Start Essentials**

Although there are many features, techniques, and nuances associated with deploying an application using Java Web Start, there are four essential elements. First, a Java Web Start application must be packaged in a JAR file. Second, the JAR file should be signed. Third, a JNLP file must be created that specifies the application’s launch information. Finally, typically you will create a link to the JNLP file that launches the application. Each is briefly described here.

**Java Web Start Apps Require a JAR File**

All Java Web Start applications must be packaged in a JAR file. As explained earlier in this book, JAR stands for Java ARchive. A JAR file is created by use of the **jar** command-line tool. When creating a JAR file for Java Web Start, you will specify all of the files, such as classes and resources, used by the application, and information to include in the application’s manifest. The manifest contains information about the JAR files, including the security setting.

The **jar** tool supports many options, but for simple applications, you will only need to use three. They are **c**, **f**, and **m**. The **c** option tells **jar** to create an archive, **f** specifies the name of the archive, and **m** tells **jar** to include the information in the specified manifest file. For example, the following command line creates a JAR file called **MyJar.jar** that contains the class in **MyClass.class** and includes the manifest
information specified by MyMan.txt.

```
jar cfm MyJar.jar MyMan.txt MyClass.class
```

Notice that each filename is specified in the same order as the option list.

**Java Web Start Apps Are Signed**

In general, a Java Web Start app must be signed using a valid *certificate*. This is done by signing the application’s JAR file. In simplified terms, signing identifies the owner of an application. It also helps to ensure the integrity of the files associated with the application because the signed JAR file will be invalid if it has been changed after it is signed. The certificate must be obtained from a legitimate, third-party certificate authority. Typically, such certificates are not free and must be purchased.

Before moving on, it is important to mention a special type of certificate referred to as “self-signed.” A “self-signed” certificate is simply a certificate created by you instead of being obtained from a certificate authority. At the time of this writing, it is possible to sign a Java Web Start application using a self-signed certificate. It is important to understand that for modern versions of Java, a self-signed application will be prevented from executing unless it is explicitly specified in the Exception Site List in the Java Control Panel. Even then, you will still see a security prompt when you try to run the application. As a result, a self-signed application *should not* be used for deployment. This is especially true for commercial applications. Remember, all commercial Java Web Start applications must be signed with a valid, recognized certificate. That said, in some cases self-signing can be helpful when learning about Java Web Start or when developing and debugging Java Web Start applications.

To sign JAR files you will use the **jarsigner** command-line tool. Before you can use **jarsigner**, you need to have a certificate. As just explained, for general deployment, especially for commercial code, you must use a certificate from a third-party certificate authority. However, when learning or experimenting, you can obtain a self-signed certificate by use of the **keytool** command-line tool. In Java, digital signatures are based on the public/private key security mechanism. The **keytool** works with a *keystore* file that holds the keys and manages certificates. The example shown later in this appendix demonstrates the use of both **jarsigner** and **keytool** to self-sign the sample application.

---

**NOTE** At the time of this writing, it is technically possible to use an unsigned JAR file with Java Web Start if the JNLP file is included in the Exception Site List.
of the Java Control Panel. Of course, deploying an unsigned application is, in the strongest possible terms, not advised.

Java Web Start Relies on JNLP

A Java Web Start application is launched by use of a JNLP file. JNLP stands for Java Network Launch Protocol. A JNLP file is an XML file that uses the \texttt{jnlp} element and has the \texttt{.jnlp} extension. Within the \texttt{jnlp} element, the deployment needs of a Java Web Start application are described. Although the \texttt{jnlp} element supports many options, for simple applications you will need to use only a few. For example, you will typically need to specify a description of the application, the resources that it uses, and information about the application. For instance, here is a simple JNLP file that launches the Swing \texttt{JLisDemo} program from Chapter 32.

```xml
<?xml version="1.0" encoding="UTF-8"?>

<jnlp href="JListDemo.jnlp" spec="6.0+">

  <!-- This describes the app. -->
  <application-desc main-class="JListDemo">
  </application-desc>

  <!-- Resources required by app. -->
  <resources>
    <!-- This specifies JListDemo's jar file. -->
    <jar href="JListDemo.jar" main="true"/>

    <!-- Specify a minimum version for Java -->
    <java version="1.8+"/>
  </resources>

  <!-- Information related to the app. -->
  <information>
    <!-- This info is shown in the cache list of the Java control panel. -->
    <title>JListDemo Application</title>
    <vendor>Self</vendor>

    <!-- The following allows offline execution -->
    <offline-allowed/>
  </information>

</jnlp>
```
Let's take a close look at the contents of this file. The file begins by specifying the minimal XML version and the UTF encoding. While not required, this is the recommended procedure. The values shown here are common, but you can adjust them as required based on the needs of your specific application. Inside the jnlp element, the href attribute specifies this JNLP file’s name. The minimum JNLP version number is specified by the spec attribute. In this example, 6.0 or greater is indicated. The version can be changed to fit your needs.

The application is described by application-desc. Notice that it identifies the main class of the application with the main-class attribute. The resources for the application are specified by resources. In this example, the JAR file for the application is indicated with the jar element. The minimum version of Java required to execute the application is specified by the java element. (In JNLP versions prior to 6, this element is called j2se and this name is still allowed.) Here, Java 8 is specified as the minimum version, but this can be changed to best fit the requirements of your application. In general, you should use the lowest version number that will work with your application.

Information pertaining to the application is contained in the information element. Here, the name and vendor of the application are specified. Also note that the application can be run offline because the offline-allowed element is included. Offline execution is especially useful for stand-alone programs that do not require Internet access to run.

It is important to state that the JNLP element supports more options and attributes than shown here. You will want to explore them in detail. Precisely tailoring the JNLP file for your application produces the best user experience.

One last point: Although a JNLP file is used to launch an application from within a browser, the application runs outside the browser. Thus, using JNLP to launch an application eliminates the need for the Java browser plug-in. This is one of the primary benefits of Java Web Start.

**Linking to the Java Web Start JNLP File**

In general, you will provide a link in a web page that launches the application. Here is a very simple one:

```html
<body>
<a href="jnlp-path">Launch App</a>
</body>
```

Here, jnlp-path specifies the path to the JNLP file for the application that you want to launch. Replace jnlp-path with the actual path to your JNLP file. When this link is
clicked, the browser is redirected to the specified JNLP file and Java Web Start is used to launch the program. The program will run on the desktop, as explained earlier. Thus, you can leave the page the link is on, and the program remains active until you close it.

**Experimenting with Java Web Start Using the Local File System**

In this section we will develop a simple Java Web Start example that you can try. As explained earlier, Java Web Start applications are normally downloaded from the network. However, assuming that your browser enables you to open a file, it is possible to experiment with Java Web Start by running the application from the local file system. Doing so gives you an easy way to see how Java Web Start works without having to use a web server. It also lets you run an application in much the same way that a user of your program will, by clicking on a link on a web page.

As mentioned earlier, applications deployed by Java Web Start are, essentially, normal Java applications. Thus, Swing and JavaFX programs can be used with Java Web Start. In this example, we will use the JavaFX **ToggleButtonDemo** program shown in Chapter 35. Although the process involves several steps, once you have worked through the procedure you will have a better idea of how Java Web Start works.

Here are the steps that you will follow to create and deploy **ToggleButtonDemo** from a file on your machine.

1. Create a JAR file for **ToggleButtonDemo** called **ToggleButtonDemo.jar**.
2. Create a keystore that contains a self-signed certificate and sign **ToggleButtonDemo.jar**.
3. Create a JNLP file called **ToggleButtonDemo.jnlp** that describes and launches **ToggleButtonDemo**.
4. Create a short HTML file called **StartTBD.html** that contains a link to **ToggleButtonDemo.jnlp**.
5. Add **ToggleButtonDemo.jnlp** to the Exception Site List in the Java Control Panel.
6. In your browser, open **StartTBD.html** and then click on the link. After a security check, **ToggleButtonDemo** will execute on the desktop (not in the browser, the way applets do).

The following sections walk through these steps in detail.
Before we begin, it is important to point out that not all of these steps are necessarily required to run a Java Web Start application from the local file system. For example, at the time of this writing self-signing an application provides no benefit. Self-signing is included here simply as a way to demonstrate signing a JAR file. Also, an HTML file may not be technically required because it may be possible to execute the JNLP file directly. All steps are shown, however, because they help provide insight into the process. Furthermore, in the future, additional steps or a modified procedure may be required.

Create a JAR File for ToggleButtonDemo

First, if you have not already done so, using the code shown in Chapter 35, compile ToggleButtonDemo.java. This will create two class files: ToggleButtonDemo.class and ToggleButtonDemo$1.class. The first contains the main class of the application. The second contains the anonymous inner class used by the action event handler. Both of these classes are required by the application. As such, both will need to be included in the application’s JAR file.

To create the JAR file for an application, you will use the jar command. Here is the form we will use for the ToggleButtonDemo program:

```
jar cfm ToggleButtonDemo.jar MyMan.txt ToggleButtonDemo.class ToggleButtonDemo$1.class
```

Here, the option c tells jar to create a JAR file. The f option specifies the name of the file, which is ToggleButtonDemo.jar in this case. The m option causes the information in MyMan.txt to be included in the manifest information associated with the JAR file.

A JAR file’s manifest contains information related to the file. All JAR files have a manifest, and the m option causes the information in the specified text file to be added to it. For ToggleButtonDemo, create the following file called MyMan.txt:

```
Main-Class: ToggleButtonDemo
Permissions: sandbox
```

This specifies that the main class of the program is ToggleButtonDemo and that execution of the program is restricted to the sandbox, which is Java’s most restrictive setting. This setting must match that specified by the application’s JNLP file, which is sandbox by default.

Create a Keystore and Sign ToggleButtonDemo.jar
For all modern versions of Java, a Java Web Start application must be signed with a valid security certificate. A certificate identifies the owner of the application, and signing helps to ensure the integrity of its JAR file. In Java, certificates are based on a public/private key security mechanism. The keys are stored in a special file called a keystore. Before you can sign an application, you need to create a keystore that contains a certificate. Keystores and certificates are managed by using keytool, which is provided with the JDK.

As explained earlier, for general deployment, you will need a certificate obtained from a legitimate third-party certificate authority. However, you can gain insight into the signing process by using a self-signed certificate. Remember, a self-signed application is not suitable for distribution because it will cause a security prompt that discourages the use of your application. It also may be blocked completely. However, using a self-signed certificate gives you an easy, cost-free way to see JAR signing in action.

As you might expect, keytool supports a number of options, but only a few are needed for the purposes of this example. Here is one approach you can use:

keytool -genkeypair -alias devName -keystore devKeys

Here, genkeypair tells keytool to generate a new key pair and to create a self-signed certificate with that pair. The name you specify after the alias option, in this case devName, identifies the entry in the keystore. The name of the keystore is specified by keystore and is devKeys in this case.

After you enter this command, you will be prompted for the following information: a password, your name, the name of your organizational unit, the name of the organization, the city, the state, and a country code (which for the United States is US). This command then automatically creates a self-signed certificate using information you specified. Be sure to remember the password because it will be needed by the next step.

**NOTE** Versions of keytool prior to Java 6 required the use of the -selfcert option to generate a self-signed certificate.

Now that you have a certificate, you can use jarsigner to sign ToggleButtonDemo.jar. This tool also supports many options, but for this example only one is needed. It specifies the keystore:

jarsigner -keystore devKeys ToggleButtonDemo.jar devName

Here, the keystore option specifies the keystore file, which is devKeys in this example. This is followed by the name of the JAR file to sign, which is
ToggleButtonDemo.jar. Finally, the certificate alias is specified. When you execute this command, you will be prompted for the password you specified in the previous step. Understand that any time you change the ToggleButtonDemo.jar file, it must be re-signed.

**REMEMBER** Although self-signing is helpful when demonstrating the JAR signing procedure, a self-signed certificate must not be used for actual application deployment. A certificate obtained from a valid certificate authority is required. Furthermore, a self-signed application that you did not create constitutes a security risk. Therefore, as a general rule, you should exercise great caution before attempting to run self-signed applications that you did not create.

**Create a JNLP File for ToggleButtonDemo**

The next step is to create a JNLP file that will launch ToggleButtonDemo. Here is the one shown earlier. Although it is very simple, it is sufficient for this example. Call this file ToggleButtonDemo.jnlp.
Create a Short HTML File Called StartTBD.html

Although it is often possible to use a JNLP file directly from the Web, usually a link is provided to launch the application. Here is a very simple one for ToggleButtonDemo:

```html
<?xml version="1.0" encoding="UTF-8"?>

<jnlp href="ToggleButtonDemo.jnlp" spec="6.0+">
   <!-- This describes the app. -->
   <application-desc main-class="ToggleButtonDemo">
   </application-desc>

   <!-- Resources required by app. -->
   <resources>
      <!-- This specifies ToggleButtonDemo's jar file. -->
      <jar href="ToggleButtonDemo.jar" main="true"/>

      <!-- Specify a minimum version for Java -->
      <java version="1.8+"/>
   </resources>

   <!-- Information related to the app. -->
   <information>
      <!-- This info is shown in the cache list of the Java control panel. -->
      <title>ToggleButtonDemo Application</title>
      <vendor>Self</vendor>

      <!-- The following allows offline execution -->
      <offline-allowed/>
   </information>

</jnlp>
```

Call this file StartTBD.html. When you click on the link, the browser is redirected to ToggleButtonDemo.jnlp and Java Web Start is used to launch the program. It will run on the desktop, as explained earlier. Thus, you can leave the page the link is on, and the program remains active until you close it.
Add ToggleButtonDemo.jnlp to the Exception Site List in the Java Control Panel

Because ToggleButtonDemo.jar was self-signed, and because it will be executed from the local file system, you will need to add the URL of ToggleButtonDemo.jnlp to the Exception Site List maintained by the Java Control Panel. (The Exception Site List was added to Java in Java 7, update 51.) Assuming that ToggleButtonDemo.jnlp is contained in the C:\Java\MyDevFiles directory, you would add the following to the Exception Site List:

FILE:/C:\Java\MyDevFiles\ToggleButtonDemo.jnlp

Here, FILE: denotes a file on the local file system. For normal deployment, you would specify a network address.

NOTE As a general rule, a URL in the Exception Site List that uses the FILE: prefix (i.e., one that refers to a file on the local file system) constitutes a security risk. Therefore, you should use great caution before adding such a URL to the Exception Site List for programs that you did not create.

Execute ToggleButtonDemo via Your Browser

At this point, you can launch ToggleButtonDemo from your browser. To do so, open the ToggleButtonDemo.html file in your browser. For example, in Internet Explorer, use the Open option in the File menu. (As mentioned at the start of this section, this example requires that your browser allows you to open a file on the local file system.) Once the file is displayed, click the Launch ToggleButtonDemo App link. Even though you have added ToggleButtonDemo.jnlp to the Exception Site List, you may still receive a security prompt the first time you run the program. After responding to a security prompt, ToggleButtonDemo will run. It will look exactly like it does when run normally from the command line, as you did in Chapter 35.

NOTE Remember, executing a Java Web Start application from a file on the local file system and using a self-signed certificate are for development, debugging, experimenting, and learning purposes only. For actual deployment, a certificate from a recognized authority is required, and the application will be deployed via the network.

Running a Java Web Start Application Using
**javaws**

When developing Java Web Start applications, it is not necessary to use a browser to run your application. Instead, you can use the `javaws` tool to run the application directly from the command line. Simply specify the name of the JNLP file. For example, assuming that `ToggleButtonDemo.jnlp` and `ToggleButtonDemo.jar` are in your current working directory, then:

```
javaws ToggleButtonDemo.jnlp
```

causes the `ToggleButtonDemo` program to be executed without the use of a browser or an HTML file. This can enable faster compile/test/debug cycles. Of course, security requirements will apply.

**Using Java Web Start with an Applet**

Although applets are being phased out, they are currently still supported by Java Web Start and can be run by a JNLP file. You may see this approach in legacy code. The element that describes an applet is called `applet-desc`. When updating older code you should rework an applet into an application and specify it with `application-desc`, as used earlier.
APPENDIX
C Introducing JShell

Beginning with JDK 9, Java has included a tool called JShell. It provides an interactive environment that enables you to quickly and easily experiment with Java code. JShell implements what is referred to as read-evaluate-print loop (REPL) execution. Using this mechanism, you are prompted to enter a fragment of code. This fragment is then read and evaluated. Next, JShell displays output related to the code, such as the output produced by a `println()` statement, the result of an expression, or the current value of a variable. JShell then prompts for the next piece of code, and the process continues (i.e., loops). In the language of JShell, each code sequence you enter is called a snippet.

A key point to understand about JShell is that you do not need to enter a complete Java program to use it. Each snippet you enter is simply evaluated as you enter it. This is possible because JShell handles many of the details associated with a Java program for you automatically. This lets you concentrate on a specific feature without having to write a complete program, which makes JShell especially helpful when you are first learning Java.

As you might expect, JShell can also be useful to experienced programmers. Because JShell stores state information, it is possible to enter multiline code sequences and run them inside JShell. This makes JShell quite useful when you need to prototype a concept because it lets you interactively experiment with your code without having to develop and compile a complete program.

This appendix introduces JShell and explores several of its key features, with the primary focus being on those features most useful to beginning Java programmers.

**JShell Basics**

JShell is a command-line tool. Thus, it runs in a command-prompt window. To start a JShell session, execute `jshell` from the command line. After doing so, you will see the JShell prompt:

```
jshell>
```

When this prompt is displayed, you can enter a code snippet or a JShell command. In its simplest form, JShell lets you enter an individual statement and immediately see the result. To begin, think back to the first example Java program in this book. It
In this program, only the `println()` statement actually performs an action, which is displaying its message on the screen. The rest of the code simply provides the required class and method declarations. In JShell, it is not necessary to explicitly specify the class or method in order to execute the `println()` statement. JShell can execute it directly on its own. To see how, enter the following line at the JShell prompt:

```java
System.out.println("This is a simple Java program.");
```

Then, press enter. This output is displayed:

```
This is a simple Java program.
```

As you can see, the call to `println()` is evaluated and its string argument is output. Then, the prompt is redisplayed.

Before moving on, it is useful to explain why JShell can execute a single statement, such as the call to `println()`, when the Java compiler, `javac`, requires a complete program. JShell is able to evaluate a single statement because JShell automatically provides the necessary program framework for you, behind the scenes. This consists of a `synthetic class` and a `synthetic method`. Thus, in this case, the `println()` statement is embedded in a synthetic method that is part of a synthetic class. As a result, the preceding code is still part of a valid Java program even though you don’t see all of the details. This approach provides a very fast and convenient way to experiment with Java code.

Next, let’s look at how variables are supported. In JShell, you can declare a variable, assign the variable a value, and use it in any valid expressions. For example, enter the following line at the prompt:

```java
int count;
```

After doing so you will see the following response:
count ==> 0

This indicates that count has been added to the synthetic class and initialized to zero. Furthermore, it has been added as a static variable of the synthetic class.

Next, give count the value 10 by entering this statement:

count = 10;

You will see this response:

count ==> 10

As you can see, count’s value is now 10. Because count is static, it can be used without reference to an object.

Now that count has been declared, it can be used in an expression. For example, enter this println() statement:

System.out.println("Reciprocal of count: " + 1.0 / count);

JShell responds with:

Reciprocal of count: 0.1

Here, the result of the expression 1.0 / count is 0.1 because count was previously assigned the value 10.

In addition to demonstrating the use of a variable, the preceding example illustrates another important aspect of JShell: it maintains state information. In this case, count is assigned the value 10 in one statement and then this value is used in the expression 1.0 / count in the subsequent call to println() in a second statement. Between these two statements, JShell stores count’s value. In general, JShell maintains the current state and effect of the code snippets that you enter. This lets you experiment with larger code fragments that span multiple lines.

Before moving on, let’s try one more example. In this case, we will create a for loop that uses the count variable. Begin by entering this line at the prompt:

for(count = 0; count < 5; count++)

At this point, JShell responds with the following prompt:

...>

This indicates that additional code is required to finish the statement. In this case, the target of the for loop must be provided. Enter the following:

System.out.println(count);
After entering this line, the `for` statement is complete and both lines are executed. You will see the following output:

```
0
1
2
3
4
```

In addition to statements and variable declarations, JShell lets you declare classes and methods, and use import statements. Examples are shown in the following sections. One other point: Any code that is valid for JShell will also be valid for compilation by `javac`, assuming the necessary framework is provided to create a complete program. Thus, if a code fragment can be executed by JShell, then that fragment represents valid Java code. In other words, JShell code is Java code.

## List, Edit, and Rerun Code

JShell supports a large number of commands that let you control the operation of JShell. At this point, three are of particular interest because they let you list the code that you have entered, edit a line of code, and rerun a code snippet. As the subsequent examples become longer, you will find these commands to be very helpful.

In JShell, all commands start with a `/` followed by the command. Perhaps the most commonly used command is `/list`, which lists the code that you have entered. Assuming that you have followed along with the examples shown in the preceding section, you can list your code by entering `/list` at this time. Your JShell session will respond with a numbered list of the snippets you entered. Pay special attention to the entry that shows the `for` loop. Although it consists of two lines, it constitutes one statement. Thus, only one snippet number is used.

You can edit a snippet by using the `/edit` command. This command causes an edit window to open in which you can modify your code. The `/edit` command has three forms. First, if you specify `/edit` by itself, the edit window contains all of the lines you have entered and lets you edit any part of it. Second, you can specify a specific snippet to edit by using `/edit n`, where `n` specifies the snippet’s number. For example, to edit snippet 3, use `/edit 3`. Finally, you can specify a named element, such as a variable. For example, to change the value of `count`, use `/edit count`.

As you have seen, JShell executes code as you enter it. However, you can also rerun what you have entered. To rerun the last fragment that you entered, use `/!`. To rerun a specific snippet, specify its number using this form: `/n`, where `n` specifies the
snippet to run. For example, to rerun the fourth snippet, enter /4. You can rerun a snippet by specifying its position relative to the current fragment by use of a negative offset. For example, to rerun a fragment that is three snippets before the current one, use /-3.

There is one other important command that you need to know about now: /exit. This terminates JShell.

Add a Method

As explained in Chapter 6, methods occur within classes. However, when using JShell it is possible to experiment with a method without having to explicitly declare it within a class. As mentioned earlier, this is because JShell automatically wraps code fragments within a synthetic class. As a result, you can easily and quickly write a method without having to provide a class framework. You can also call the method without having to create an object. This feature of JShell is especially beneficial when learning the basics of methods in Java or when prototyping new code. To understand the process, we will work through an example.

To begin, start a new JShell session and enter the following method at the prompt:

double reciprocal(double val) {
    return 1.0/val;
}

This creates a method that returns the reciprocal of its argument. After you enter this, JShell responds with the following:

| created method reciprocal(double)

This indicates the method has been added to JShell’s synthetic class and is ready for use.

To call reciprocal(), simply specify its name, without any object or class reference. For example, try this:

System.out.println(reciprocal(4.0));

JShell responds by displaying 0.25.

You might be wondering why you can call reciprocal() without using the dot operator and an object reference. Here is the answer. When you create a stand-alone method in JShell, such as reciprocal(), JShell automatically makes that method a static member of the synthetic class. As you know from Chapter 7, static methods are called relative to their class, not on a specific object. So, no object is required.
This is similar to the way that stand-alone variables become `static` variables of the synthetic class, as described earlier.

Another important aspect of JShell is its support for a forward reference inside a method. This feature lets one method call another method, even if the second method has not yet been defined. This enables you to enter a method that depends on another method without having to worry about which one you enter first. Here is a simple example. Enter this line in JShell:

```java
void myMeth() { myMeth2(); }
```

JShell responds with the following:

```
| created method myMeth(), however, it cannot be invoked until myMeth2() is declared
```

As you can see, JShell knows that `myMeth2()` has not yet been declared, but it still lets you define `myMeth()`. As you would expect, if you try to call `myMeth()` at this time, you will see an error message since `myMeth2()` is not yet defined, but you are still able to enter the code for `myMeth()`.

Next, define `myMeth2()` like this:

```java
void myMeth2() { System.out.println("JShell is powerful."); }
```

Now that `myMeth2()` has been defined, you can call `myMeth()`.

In addition to its use in a method, you can use a forward reference in a field initializer in a class.

## Create a Class

Although JShell automatically supplies a synthetic class that wraps code snippets, you can also create your own class in JShell. Furthermore, you can instantiate objects of your class. This allows you to experiment with classes inside JShell’s interactive environment. The following example illustrates the process.

Start a new JShell session and enter the following class, line by line:
When you finish entering the code, JShell will respond with

| created class MyClass |

Now that you have added **MyClass**, you can use it. For example, you can create a **MyClass** object with the following line:

MyClass ob = new MyClass(10.0);

JShell will respond by telling you that it added `ob` as a variable of type **MyClass**.

Next, try the following line:

System.out.println(ob.reciprocal());

JShell responds by displaying the value 0.1.

As a point of interest, when you add a class to JShell, it becomes a **static** nested member of a synthetic class.

### Use an Interface

Interfaces are supported by JShell in the same way as classes. Therefore, you can declare an interface and implement it by a class within JShell. Let’s work through a simple example. Before beginning, start a new JShell session.

The interface that we will use declares a method called `isLegalVal()` that is used to determine if a value is valid for some purpose. It returns **true** if the value is legal and **false** otherwise. Of course, what constitutes a legal value will be determined by each class that implements the interface. Begin by entering the following interface into JShell:

```java
interface MyIF {
    boolean isLegalVal(double v);
}
```

JShell responds with
Next, enter the following class, which implements MyIF:

class MyClass implements MyIF {
    double start;
    double end;
    
    MyClass(double a, double b) { start = a; end = b; }
    
    // Determine if v is within the range start to end, inclusive.
    public boolean isLegalVal(double v) {
        if ((v >= start) && (v <= end)) return true;
        return false;
    }
}

JShell responds with

|  created class MyClass

Notice that MyClass implements isLegalVal() by determining if the value v is within the range (inclusive) of the values in the MyClass instance variables start and end.

Now that both MyIF and MyClass have been added, you can create a MyClass object and call isLegalVal() on it, as shown here:

MyClass ob = new MyClass(0.0, 10.0);
System.out.println(ob.isLegalVal(5.0));

In this case, the value true is displayed because 5 is within the range 0 through 10.

Because MyIF has been added to JShell, you can also create a reference to an object of type MyIF. For example, the following is also valid code:

MyIF ob2 = new MyClass(1.0, 3.0);
boolean result = ob2.isLegalVal(1.1);

In this case, the value of result will be true and will be reported as such by JShell.

One other point: enumerations and annotations are supported in JShell in the same way as classes and interfaces.
Evaluate Expressions and Use Built-in Variables

JShell includes the ability to directly evaluate an expression without it needing to be part of a full Java statement. This is especially useful when you are experimenting with code and don’t need to execute the expression in a larger context. Here is a simple example. Using a new JShell session, enter the following at the prompt:

```
3.0 / 16.0
```

JShell responds with:

```
$1 ==> 0.1875
```

As you can see, the result of the expression is computed and displayed. However, note that this value is also assigned to a temporary variable called `$1`. In general, each time an expression is evaluated directly, its result is stored in a temporary variable of the proper type. Temporary variable names all begin with a `$` followed by a number, which is increased each time a new temporary variable is needed. You can use these temporary variables like any other variable. For example, the following displays the value of `$1`, which is 0.1875 in this case.

```
System.out.println($1);
```

Here is another example:

```
double v = $1 * 2;
```

Here, the value `$1` times 2 is assigned to `v`. Thus, `v` will contain 0.375.

You can change the value of a temporary variable. For example, this reverses the sign of `$1`:

```
$1 = -$1
```

JShell responds with

```
$1 ==> -0.1875
```

Expressions are not limited to numeric values. For example, here is one that concatenates a `String` with the value returned by `Math.abs($1)`.

```
"The absolute value of $1 is " + Math.abs($1)
```
This results in a temporary variable that contains the string

The absolute value of $1$ is 0.1875

**Importing Packages**

As described in Chapter 9, an `import` statement is used to bring members of a package into view. Furthermore, any time you use a package other than `java.lang`, you must import it. The situation is much the same in JShell except that by default, JShell imports several commonly used packages automatically. These include `java.io` and `java.util`, among several others. Since these packages are already imported, no explicit `import` statement is required to use them.

For example, because `java.io` is automatically imported, the following statement can be entered:

```java
FileInputStream fin = new FileInputStream("myfile.txt");
```

Recall that `FileInputStream` is packaged in `java.io`. Since `java.io` is automatically imported, it can be used without having to include an explicit `import` statement. Assuming that you actually have a file called `myfile.txt` in the current directory, JShell will respond by adding the variable `fin` and opening the file. You can then read and display the file by entering these statements:

```java
int i;
do {
    i = fin.read();
    if(i != -1) System.out.print((char) i);
} while(i != -1);
```

This is the same basic code that was discussed in Chapter 13, but no explicit `import java.io` statement is required.

Keep in mind that JShell automatically imports only a handful of packages. If you want to use a package not automatically imported by JShell, then you must explicitly import it as you do with a normal Java program. One other point: you can see a list of the current imports by using the `/imports` command.

**Exceptions**

In the I/O example shown in the preceding section on imports, the code snippets also illustrate another very important aspect of JShell. Notice that there are no `try/catch` blocks that handle I/O exceptions. If you look back at the similar code in Chapter 13,
the code that opens the file catches a `FileNotFoundException`, and the code that reads the file watches for an `IOException`. The reason that you don’t need to catch these exceptions in the snippets shown earlier is because JShell automatically handles them for you. More generally, JShell will automatically handle checked exceptions in many cases.

### Some More JShell Commands

In addition to the commands discussed earlier, JShell supports several others. One command that you will want to try immediately is `/help`. It displays a list of the commands. You can also use `/?` to obtain help. Some of the more commonly used commands are examined here.

You can reset JShell by using the `/reset` command. This is especially useful when you want to change to a new project. By use of `/reset` you avoid the need to exit and then restart JShell. Be aware, however, that `/reset` resets the entire JShell environment, so all state information is lost.

You can save a session by using `/save`. Its simplest form is shown here:

```
/save filename
```

Here, `filename` specifies the name of the file to save into. By default, `/save` saves your current source code, but it supports three options, of which two are of particular interest. By specifying `-all` you save all lines that you enter, including those that you entered incorrectly. You can use the `-history` option to save your session history (i.e., the list of the commands that you have entered).

You can load a saved session by using `/open`. Its form is shown next:

```
/open filename
```

Here, `filename` is the name of the file to load.

JShell provides several commands that let you list various elements of your work. They are shown here:

<table>
<thead>
<tr>
<th>Command</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>/types</td>
<td>Shows classes, interfaces, and enums.</td>
</tr>
<tr>
<td>/imports</td>
<td>Shows import statements.</td>
</tr>
<tr>
<td>/methods</td>
<td>Shows methods.</td>
</tr>
<tr>
<td>/vars</td>
<td>Shows variables.</td>
</tr>
</tbody>
</table>
For example, if you entered the following lines:

    int start = 0;
    int end = 10;
    int count = 5;

and then entered the `/vars` command, you would see

```
   | int start = 0;
   | int end = 10;
   | int count = 5;
```

Another often useful command is `/history`. It lets you view the history of the current session. The history contains a list of what you have typed at the command prompt.

**Exploring JShell Further**

The best way to get proficient with JShell is to work with it. Try entering several different Java constructs and watching the way that JShell responds. As you experiment with JShell, you will find the usage patterns that work best for you. This will enable you to find effective ways to integrate JShell into your learning or development process. Also, keep in mind that JShell is not just for beginners. It also excels when prototyping code. Thus, even if you are an experienced pro, you will still find JShell helpful whenever you need to explore new areas.

You will also want to closely examine the JShell commands and their options. Because JShell is new, it is likely that by the time you read this, it will include additional features. It is also likely that JShell’s features will be incorporated into Java IDEs, further streamlining the prototype/development process. JShell is an important tool that further enhances the overall Java development experience.
D  Applet Basics

As explained earlier in this book, JDK 9 deprecates the applet API. As a result, applets are not recommended for new code, with Java Web Start providing an excellent alternative. However, you may encounter legacy applets that require maintenance or that need to be converted into applications. Thus, for the benefit of those readers working with legacy applets, this appendix provides a brief introduction to the basics.

Applets are based on the Applet class. The Applet class is contained in the java.applet package. Beginning with JDK 9, this package is part of the java.desktop module. Applet contains several methods that give you detailed control over the execution of your applet. In addition, java.applet defines three interfaces, AppletContext, AudioClip, and AppletStub, which are often used by applets.

REMEMBER The Applet API has been deprecated by JDK 9, and applets are not recommended for new code.

Two Types of Applets

It is important to state at the outset that there are two varieties of applets based on Applet. The first are those that extend the Applet class directly. These applets use the Abstract Window Toolkit (AWT) to provide the graphical user interface (or use no GUI at all). This style of applet has been available since Java was first created.

The second type of applets are those that extend the Swing class JApplet, which extends Applet. Swing applets use the Swing classes to provide the GUI. Swing offers a richer and often easier-to-use user interface than does the AWT. Thus, Swing-based applets are commonplace.

This appendix begins with AWT-based applets. However, because JApplet inherits Applet, all the features of Applet are also available in JApplet, and much of the information applies to both types. Therefore, even if you are interested in only Swing applets, the information on AWT-based applets is still relevant and necessary. Understand, however, that when creating Swing-based applets, some additional constraints apply, and these are described later in this appendix.
Applet Basics

AWT-based applets are direct subclasses of **Applet**. Applets are not stand-alone programs. Instead, they run within either a web browser or an applet viewer. The illustrations shown in this appendix were created with the standard applet viewer, called **appletviewer**, provided by the JDK. Be aware, however, that beginning with JDK 9, **appletviewer** is a deprecated tool.

Unlike a Java console application, execution of an applet does not begin at **main()**. Actually, few applets even have **main()** methods. Instead, execution of an applet is started and controlled with an entirely different mechanism, which will be explained shortly. Output to an applet’s window is not performed by **System.out.println()**. Rather, in an AWT-based applet, output is handled with various AWT methods, such as **drawString()**, which outputs a string to a specified X,Y location. Input is also handled differently than in a console application, typically through an AWT-based control, such as a push button or an edit box.

There are two basic ways in which an applet can be included in a web page. The first is through the Java Network Launch Protocol (JNLP). This method offers the most flexibility, especially as it relates to rich Internet applications. Thus, JNLP was often the choice for real-world applets. (A detailed discussion of JNLP is beyond the scope of this book, but a brief introduction to JNLP is found in Appendix C.) The second basic approach to deploying an applet is to specify the applet directly in an HTML file, without the use of JNLP. Originally, this was by use of the APPLET tag, and this is the way applets were launched when Java was first created. When an APPLET tag is encountered in the HTML file, the specified applet will be executed by a Java-enabled web browser. Although the APPLET tag is traditional, the OBJECT tag offers a standardized alternative, and you will likely encounter it, especially in newer HTML files.

When developing applets, you can use either the APPLET or OBJECT tag to easily view and test the applet. To do so, simply include a comment at the head of your Java source code file that contains the APPLET or OBJECT tag. This way, your code is documented with the necessary HTML statements needed by your applet, and you can test the compiled applet by starting **appletviewer** with your Java source code file specified as the target. Here is an example of such a comment that uses the APPLET tag:

```java
/* <applet code="MyApplet" width=200 height=60>
</applet>
*/
```

This comment contains an APPLET tag that will run an applet called **MyApplet** in a
window that is 200 pixels wide and 60 pixels high. Because the inclusion of such a tag makes testing applets easier, the applets shown here will contain the appropriate, traditional APPLET tag embedded in a comment. You are free to substitute OBJECT if you desire.

NOTE For modern versions of Java, there are significant security issues surrounding applets. For example, beginning with the release of Java 7, update 21, Java applets must be signed to prevent security warnings when run in a browser. In fact, in some cases, the applet may be prevented from running. Consult Oracle’s documentation for the latest security information pertaining to applets. Fortunately, if you simply want to try the examples shown in this appendix, you can easily do so by using appletviewer.

The Applet Class

The Applet class encapsulates an applet. It defines a number of methods. The most fundamental are those methods that control an applet’s execution, such as starting and stopping. These are the life cycle methods init(), start(), stop(), and destroy(). Other methods load and display images, load and play audio clips, access parameters, and so on. Remember, all of these methods, and the entire applet API, are deprecated as of JDK 9. Thus, compiling an applet with JDK 9 or later will generate deprecation warnings.

Applet extends the AWT class Panel. In turn, Panel extends Container, which extends Component. These classes provide support for the AWT-based graphical interface. Thus, Applet provides all of the necessary support for window-based activities and handling events. (An overview of the AWT is presented in Chapters 25 and 26.)

Applet Architecture

As a general rule, an applet is a GUI-based program. As such, its architecture is different from console-based programs. First, applets are event driven. Here is how the process works. An applet waits until an event occurs. The run-time system notifies the applet about an event by calling an event handler that has been provided by the applet. Once this happens, the applet must take appropriate action and then quickly return. This is a crucial point. For the most part, your applet should not enter a “mode” of operation in which it maintains control for an extended period. Instead, it must perform specific actions in response to events and then return control to the run-time system. In those situations in which your applet needs to perform a
repetitive task on its own (for example, displaying a scrolling message across its window), you must start an additional thread of execution.

Second, the user initiates interaction with an applet—not the other way around. As you know, in a console-based program, when the program needs input, it will prompt the user and then call some input method, such as `readLine()` . This is not the way it works in an applet. Instead, the user interacts with the applet as he or she wants, when he or she wants. These interactions are sent to the applet as events to which the applet must respond. For example, when the user clicks the mouse inside the applet’s window, a mouse-clicked event is generated. If the user presses a key while the applet’s window has input focus, a keypress event is generated. Applets can contain various controls, such as push buttons and check boxes. When the user interacts with one of these controls, an event is generated. For AWT-based applets, the basic AWT GUI is used. For Swing applets, the Swing GUI is used.

**An Applet Skeleton**

All but the most trivial applets override a set of methods that provide the basic mechanism by which the browser or applet viewer interfaces to the applet and controls its execution. Four of these methods, `init()`, `start()`, `stop()`, and `destroy()`, apply to all applets. These are the applet’s life cycle methods, and they are defined by `Applet`. Default implementations for these methods are provided. Applets do not need to override those methods they do not use. However, only very simple applets will not need to define all of them. AWT-based applets will often override the `paint()` method, which is defined by the AWT `Component` class. This method is called when the output displayed in the applet’s window must be redisplayed. (As explained later, Swing-based applets use a different mechanism and will not usually override `paint()`.)

The four life cycle methods plus `paint()` can be assembled into the skeleton shown here:
Although this skeleton is quite short, it can be compiled and run. When run, it generates the following window when viewed with `appletviewer`. Of course, in this and the subsequent example, the precise look of the `appletviewer` frame may differ based on your execution environment.
Applet Initialization and Termination

It is important to understand the order in which the various methods shown in the preceding skeleton are called. When an applet begins, the following methods are called, in this sequence:

1. init()
2. start()
3. paint()

When an applet is terminated, the following sequence of method calls takes place:

1. stop()
2. destroy()

Let’s look more closely at these methods.

init()
The init() method is the first method to be called. This is where applet initialization is performed. This method is called only once during the execution of the applet.

start()
The start() method is called after init(). It is also called to restart an applet after it has been stopped. Whereas init() is called once—the first time an applet is loaded—start() is called each time an applet’s HTML document is displayed. So, if a user leaves a web page and comes back, the applet resumes execution at start().

paint()
The `paint()` method is called each time an AWT-based applet’s output must be redrawn. As explained, `paint()` is not specified by `Applet`, but is inherited from `Component`. Thus, it works in an AWT-based applet the same as it does in an AWT-based GUI application as described in Chapter 25. Furthermore, to request repainting, call `repaint()`, as also described in Chapter 25. Remember, the `paint()` method is needed only in AWT-based applets that draw output to their window. In the preceding example, `paint()` is used to display a string in the applet’s window. If the applet uses only controls, for example, then `paint()` is not needed.

`stop()`

The `stop()` method is called when a web browser leaves the HTML document containing the applet—when it goes to another page, for example. When `stop()` is called, the applet is probably running. An important use of `stop()` is to suspend threads that don’t need to run when the applet is not visible. If the user returns to the page, the threads can be restarted when `start()` is called.

`destroy()`

The `destroy()` method is called when the environment determines that the applet needs to be removed completely from memory. At this point, any resources used by the applet should be released. The `stop()` method is always called before `destroy()`.

Swing Applets

The second type of applet you may encounter is Swing-based. Swing-based applets are similar to AWT-based applets, but with an important difference: a Swing applet extends `JApplet` rather than `Applet`. Because `JApplet` is derived from `Applet` it includes all of the functionality found in `Applet` and adds support for Swing. `JApplet` is a top-level Swing container, which means that it is not derived from `JComponent`. Because `JApplet` is a top-level container, it includes the various panes described in Chapter 31. This means that all components are added to `JApplet`’s content pane in the same way that components are added to `JFrame`’s content pane.

Swing applets use the same four life cycle methods as just described: `init()`, `start()`, `stop()`, and `destroy()`. Of course, you need override only those methods that are required by your applet. Painting is accomplished differently in Swing than it is in the AWT, and a Swing applet will not normally override the `paint()` method. If you need to paint directly to the applet window, then you will typically override its `paintComponent()` method, as described in Chapter 31.
One other point: All interaction with components in a Swing applet must take place on the event-dispatching thread, as is the case with all Swing applications.

Here is an example of a Swing applet. It uses two buttons and a text field. Each time a button is pressed, the action is displayed in the text field. Notice that only \texttt{init( )} is overridden. There is no need to override the other life cycle methods because their default versions are adequate.

```java
// A simple Swing-based applet
import javax.swing.*;
import java.awt.*;
import java.awt.event.*;

/*
<applet code="MySwingApplet" width=220 height=90>
</applet>
*/

public class MySwingApplet extends JApplet {
    JButton jbtnAlpha;
    JButton jbtnBeta;
```
JLabel jlab;

// Initialize the applet.
public void init() {
    try {
        SwingUtilities.invokeLater(new Runnable() {
            public void run() {
                makeGUI(); // initialize the GUI
            }
        });
    } catch(Exception exc) {
        System.out.println("Can't create because of "+ exc);
    }
}

// This applet does not need to override start(), stop(),
// or destroy().

// Setup and initialize the GUI.
private void makeGUI() {
    // Set the applet to use flow layout.
    setLayout(new FlowLayout());

    // Make two buttons.
    jbtnAlpha = new JButton("Alpha");
    jbtnBeta = new JButton("Beta");

    // Add action listener for Alpha.
    jbtnAlpha.addActionListener(new ActionListener() {
        public void actionPerformed(ActionEvent le) {
            jlab.setText("Alpha was pressed.");
        }
    });
Here is MySwingApplet as displayed by appletviewer:

```java
// Add action listener for Beta.
btnBeta.addActionListener(new ActionListener() {
    public void actionPerformed(ActionEvent le) {
        jLab.setText("Beta was pressed.");
    }
});

// Add the buttons to the content pane.
add(btnAlpha);
add(btnBeta);

// Create a text-based label.
jLab = new JLabel("Press a button.");

// Add the label to the content pane.
add(jLab);
}
```

There are two important things to notice about this applet. First, MySwingApplet extends JApplet. As explained, all Swing-based applets extend JApplet rather than Applet. Second, the init() method initializes the Swing components on the event-dispatching thread by setting up a call to makeGUI(). Notice that this is accomplished through the use of invokeAndWait() rather than invokeLater(). Applets must use invokeAndWait() because the init() method must not return until the entire initialization process has been completed. In essence, the start() method cannot be called until after initialization, which means that the GUI must be fully constructed.

Inside makeGUI(), the two buttons and label are created, and the action listeners are added to the buttons. Finally, the components are added to the content pane. Although this example is quite simple, this same general approach must be used
when building any Swing GUI that will be used by an applet.
Please note that index links point to page beginnings from the print edition. Locations are approximate in e-readers, and you may need to page down one or more times after clicking a link to get to the indexed material.

&
  bitwise AND, 68, 69, 70–71
  Boolean logical AND, 77, 78, 79
  and bounded type declarations, 347
&& (short-circuit AND), 77, 79
*
  and glob syntax, 744
  multiplication operator, 29, 63, 64
  regular expression quantifier, 983
  used in import statement, 196, 331
** (glob syntax), 744
@
  annotation syntax, 35, 285
  used with tags (javadoc), 1228, 1232
|
  bitwise OR, 68, 69, 70–71
  Boolean logical OR, 77, 78
|| (short-circuit OR), 77, 79
[ ], 35, 53, 54, 56, 60, 81
  character class specification, 983, 987
^
  bitwise exclusive OR (XOR), 68, 69, 70–71
Boolean logical exclusive OR (XOR), 77, 78
character class specification, 983
: (used with a label), 106
::
    constructor reference, 35, 402, 406
    method reference, 35, 394, 400
, (comma), 35, 97, 385
    format flag, 642, 644
{ }, 26, 28, 32, 35, 47, 48, 55, 58, 83, 84, 91, 95, 221, 296, 386, 410
    used with javadoc tags, 1228
{…} anonymous inner class syntax, 799
$ used in temporary variable name, 1252
=, 29, 46, 77, 79–80
== (Boolean logical operator), 77
== (relational operator), 30, 76, 77, 268, 274
    versus equals( ), 448–449
!, 77, 78
!=, 76, 77
/, 63, 64
/* */, 26
/** */, 35, 1227
//, 27
<, 30, 76
    argument index syntax, 645–646
<>
    diamond operator (type inference), 370–371
    and generic type parameter, 338
<<?>, 286, 288, 348
<<, 68, 71–73
<=, 76
–, 63, 64
    format flag, 642
-> lambda expression arrow operator, 17, 63, 81, 380
--> 32, 63, 66–67
%
    used in format conversion specifier syntax, 633
    modulus operator, 63, 65
( format flag, 642, 644
( ), 27, 35, 82, 115, 125
   used in a lambda expression, 380, 384, 385
   used to raise the precedence of operations, 35, 43, 81, 444
. (period)
   and calling static interface methods, 213
   dot operator, 81, 113, 119, 148, 172, 196, 213
   in import statement, 196
   in multileveled package statement, 190, 196
   and nested interfaces, 203
   regular expression wildcard character, 983, 986
   separator, 35
…
   and enabling/disabling assertions syntax, 328–329
   variable-length argument syntax, 35, 158, 161
+
   addition operator, 63, 64
   concatenation operator, 29, 154–155, 443–444
   format flag, 642, 643
   regular expression quantifier, 983, 985–987
   unary plus, 63, 64
++, 32, 63, 66–68
# format flag, 642, 644
?
   regular expression quantifier, 983, 986–987
   wildcard argument specifier, 348, 351, 354, 368, 377, 744
?: (ternary if-then-else operator), 78, 80
>, 30, 76
>>>, 68, 73–74
>>>>, 68, 74–75
>=, 76
; (semicolon), 28, 35, 92, 199
   used in try-with-resources statement, 321, 678
~ (bitwise unary NOT operator), 68, 69, 70–71
_ (underscore), 34, 44, 45
   and mnemonics specification, 1171
0 (zero) format flag, 642, 644
abs( ), 133–134, 506
Abstract method(s), 183–186
    and lambda expressions, 380, 381, 382, 383
abstract type modifier, 184, 187, 202, 381
Abstract Window Toolkit. See AWT (Abstract Window Toolkit)
AbstractAction interface, 1081, 1082
AbstractButton class, 1033, 1036, 1060, 1063, 1068, 1071
AbstractCollection class, 541, 543, 550
AbstractList class, 541
AbstractMap class, 568, 570, 572
AbstractQueue class, 541
AbstractSequentialList class, 541
AbstractSet class, 541
accept( ), 556, 664, 665, 666, 675, 676, 744, 764, 962, 975, 977
Access control, 143–146
    and default access, 193, 199
    example program, 193–196
    and inheritance, 144, 146, 165–166
    and modules, 144
    and packages, 144, 189, 192–196
Access modifiers, 27, 144, 192–193
acquire( ), 908–911
Action (Swing), 1059, 1079–1084
Action interface, 1079, 1080, 1081
ActionEvent class, 772–773, 833, 857, 870, 1022, 1023, 1031, 1033, 1040
    JavaFX, 1105, 1106, 1108, 1169
ActionListener interface, 783, 833, 837, 845, 870, 1022, 1023, 1033, 1040, 1067, 1079
actionPerformed( ), 783, 833, 836, 1023, 1024, 1033, 1040, 1067, 1068, 1079, 1081, 1082–1083
adapt( ), 952
Adapter classes, 790, 794–796
add( ), 531, 532, 533, 534, 546, 553, 618, 805, 830, 836, 841, 844, 857, 861, 870, 975, 994, 995, 1019–1020, 1040, 1052, 1053, 1061, 1062, 1077, 1081, 1103, 1108, 1150, 1153, 1155, 1156, 1163, 1164, 1179
addActionListener( ), 1023
addAll( ), 531, 532, 533, 534, 975, 1104, 1108, 1150, 1163, 1164, 1169
addCookie( ), 1214, 1220
addElement( ), 594
addEventFilter( ), 1105
addExports( ), 518
addFirst( ), 539, 540, 545, 975
addItem( ), 1050
addKeyListener( ), 771
addLast( ), 539, 540, 545, 546
addListener( ), 1129, 1150
addMouseListener( ), 789–790, 799, 1074
addMouseMotionListener( ), 771, 789–790
addOpens( ), 518
addReads( ), 518
Address, Internet, 750, 751–753, 757
addSeparator( ), 1062
addTab( ), 1042
addTListener( ) 1192
addTypeListener( ), 770, 771
addUses( ), 518
AdjustmentEvent class, 773, 774, 848
AdjustmentListener interface, 783, 784, 848
adjustmentValueChanged( ), 783
Affine class, 1156
Algorithms, collection, 529, 581–586, 592
allMatch( ), 980
allocate( ), 720, 729, 731
anchor constraint field, 865–866
AND operator
   bitwise ( ), 68, 69, 70–71
   Boolean logical ( ), 77, 78, 79
   and bounded type declarations ( ), 347
   short-circuit ( ), 77, 79
AnnotatedElement interface, 291, 293, 303, 526
Annotation interface, 285, 291, 525
Annotation member, 285
assigning a value to an, 285, 294, 295
default values for an, 292–293, 295
obtaining the value of an, 287, 288

Annotation(s), 15, 284–304, 525
  built-in, 295–297
  container, 302, 303
  declaration example, 285
  and JShell, 1251
  marker, 293–294
  member. See Annotation member
  obtaining all, 290–291
  reflection to obtain, using, 286–291
  repeated, 291, 302–304
  restrictions on, 304
  retention policies, 285–286
  single-member, 294–295
  type, 297–302

annotationType( ), 285

anyMatch( ), 980

Apache Software Foundation, 1202
Apache Tomcat, 1202. See also Tomcat
API library, compact profiles of the, 334
APPEND, 494

append( ), 461, 523, 700, 853

Appendable interface, 523, 635, 693, 700, 707
appendTo( ), 494

Applet, 8–9
  deprecated, 11, 18, 1235, 1255
  Java Web Start with an, using, 1243
  unsigned, 1236
  versus Java Web Start, 1235–1236

Applet, AWT-based, 1255–1260
  architecture, 1257
  event-driven nature of the, 1257
  and the Internet, 8–9
  and main( ), 1256
  and security, 1256
signed, 1256
skeleton, 1257–1260
as source and listener for events, 1257
Applet class, 804, 1235, 1255, 1257, 1260, 1262
Applet, Swing, 1015, 1016, 1021, 1255, 1260–1262
APPLET tag, HTML, 1256
AppletContext interface, 1255
AppletStub interface, 1255
appletviewer, 1256, 1258–1259
Application class, 1097–1098, 1100
Application launcher (java). See java (Java application launcher)
apply( ), 407, 664, 665, 666, 963–964, 968
applyAsDouble( ), 664, 665, 666, 971
AreaAveragingScaleFilter class, 890
areFieldsSet Calendar class instance variable, 618
Argument(s), 118, 122
command-line, 27, 156–157
index, 645–646
lambda expressions passed as, 389–391
and overloaded constructors, 136
passing, 138–140
type. See Type argument(s)
variable-length. See Varargs
 wildcard. See Wildcard arguments
Arithmetic operators, 63–68
ArithmeticException, 219, 220, 230, 507
Array class, 526, 990
Array(s), 27, 53–60, 149, 187
boundary checks, 55
and collections, 587
constructor reference for, 406
converting collections into, 532, 543–544
copying with arraycopy( ), 495, 497–498
declaration syntax, alternative, 60
dynamic, 541–543, 550, 593–597
and the for-each loop, 99–103
and generics, 375–377
implemented as objects, 149
indexes, 53, 54
initializing, 55, 58–59
length instance variable of, 149–151
multidimensional, 56–60, 101–102
one-dimensional, 53–56
and spliterators, 590
and a stream API stream, 959
string using a byte, initializing a, 441
of strings, 156
and valueOf( ), 455
and varargs, 158
ArrayBlockingQueue class, 933
arraycopy( ), 495, 497–498
ArrayDeque class, 541, 550–551, 599
ArrayIndexOutOfBoundsException, 223, 230, 588
ArrayList class, 541–544, 560, 593, 594, 959
  example using an, 554–555
  examples using a stream API stream, 959–963, 968–972, 973–974, 976–979
Arrays class, 587–592, 959
ArrayStoreException, 230, 588
arrive( ), 920–921
arriveAndAwaitAdvance( ), 920, 921, 923, 926
arriveAndDeregister( ), 921, 923
Arrow operator (–>), 17, 63, 81, 380
ASCII character set, 41, 42, 45, 450
  and strings on the Internet, 441, 446
asIterator(), 593
asList( ), 587
Assembly language, 4, 5
assert statement, 15, 326–329
Assertions, 326–329
AssertionError, 326
Assignment operator
  =, 29, 77, 79–80
  arithmetic compound (op=), 63, 65–66
  bitwise compound, 68, 75–76
Boolean logical, 77
Atomic operations, 936–937
AtomicInteger class, 907, 937
AtomicLong class, 907, 937
AttributeView interface, 728
AudioClip interface, 1255
Autoboxing/unboxing, 15, 277, 279–284, 339–340
  Boolean and Character values, 282–283
  and collections, 544
  definition of, 279
  and error prevention, 283–284
  and expressions, 281–282
  and methods, 280–281
Autocloseable interface, 314, 320, 524, 646, 653, 676, 678, 679, 682, 693, 696, 698, 699, 700, 707, 711, 713, 720, 729, 743, 754, 765, 956
Automatic resource management (ARM), 218, 319–322, 524, 646, 756
available( ), 680–682, 713, 714
availableProcessors( ), 948
await( ), 914, 915–916, 917, 935
awaitAdvance( ), 926
awaitAdvanceInterruptibly( ), 926
AWT (Abstract Window Toolkit), 305, 769, 786, 801–802, 829, 1095
  classes, table of some, 802–804
  color system, 815
  controls. See Controls, AWT
  and fonts, 819–825
  layout managers. See Layout manager(s)
  support for imaging, 879
  support for text and graphics, 810
  and Swing, 801, 829, 1011–1012
AWTEvent class, 772, 802

B
B, 4
Base64 class, 662
BaseStream interface, 956–957, 958, 965, 967
methods, table of, 956
BASIC, 4
Basic multilingual plane (BMP), 484
BasicFileAttributes class, 726, 727, 728, 741
   methods, table of, 727
BasicFileAttributeView interface, 728
BCP 47, 626
BCPL, 4
BeanInfo interface, 1190, 1192–1193, 1194, 1196
   naming convention for a class implementing the, 1192
Beans, Java. See Java Beans
Bell curve, 626
Bell Laboratories, 6
Berkeley UNIX, 749
Berners-Lee, Tim, 757
Beyond Photography: The Digital Darkroom (Holzmann), 886
BiConsumer functional interface, 664, 975
BiFunction functional interface, 664, 963
Binary
   exponent, 45
   literals, 44
   numbers and integers, 68–69
BinaryOperator<T> predefined functional interface, 407, 664, 963
binarySearch( )
   algorithm defined by Collections, 581
   Arrays method, 587
BitSet class, 611–613
   methods, table of, 611–612
Bitwise operators, 68–76
Block lambdas, 380, 385–387. See also Lambda expression(s)
BLOCKED, 264
Blocks of code. See Code blocks
Boolean, 37
   expression, 30, 31
   literals, 45
   logical operators, 77–79
Boolean class, 277, 485
and autoboxing/unboxing, 282–283
methods, table of, 487
boolean data type, 37, 42–43, 45, 50
and relational operators, 42, 43, 76–77
booleanValue( ), 277, 487
Border interface, 1028
BorderFactory class, 1028
BorderLayout class, 802, 856–858, 1023, 1078
example with insets, 858–859
BorderPane class, 1097, 1168, 1177
methods for positioning nodes within a, 1168
boxed( ), 958
Boxing, 279
break statement, 86, 87–88, 104–108
and the for-each loop, 100–101
as form of goto, 106–108
Buffer class, 718–720
methods, table of, 718–719
Buffer, NIO, 718–720
BufferedImage class, 881
BufferedInputStream class, 307, 688–690, 739
BufferedOutputStream class, 307, 688, 690, 739
BufferedReader class, 308, 309, 310–312, 704–706, 959
BufferedWriter class, 308, 706
Buffering, double, 882–885
build( ), 492
bulkRegister( ), 927
Button class
AWT, 802, 833
JavaFX, 1105–1106, 1120, 1123
Button(s)
as event sources, 773, 782, 833, 1104, 1123, 1126
group, 1040, 1072, 1125–1126
push. See Push buttons, AWT; Push buttons, JavaFX; Push buttons, Swing
radio. See Radio buttons
Swing, 1033–1041
Swing menu items as, 1060
toggle. See Toggle button, JavaFX; Toggle button, Swing

ButtonBase class, 1105, 1123, 1125, 1132
ButtonGroup class, 1029, 1040
ButtonModel interface, 1014, 1033
ButtonUI, 1014
Byte class, 277, 278, 467, 473, 480, 481
  methods defined by, table of, 474
byte data type, 37, 38–39, 43
  and automatic type conversion, 50
  and automatic type promotion, 52, 71–72, 74–75
ByteArrayInputStream class, 307, 685–686
ByteArrayOutputStream class, 307, 686–688
ByteBuffer class, 719, 728, 729, 733
  get( ) and put( ) methods, table of, 720
Bytecode, 10–11, 13–14, 18, 26, 326, 333, 509
BYTES, 469, 480, 482
byteValue( ), 278, 468, 470, 471, 474, 475, 476, 478

C

C, 6, 8
  history of, 4–5
  and Java, 3, 5, 7, 12

C Programming Language, The (Kernighan and Ritchie), 4

C++
  history of, 5–6
  and Java, 3, 7–8, 12

C# and Java, 8

Calendar class, 616, 617, 618–621, 622, 626, 1001
  constants, 620
  methods defined by, table of a sampling of, 618–620

Call-by-reference, 138, 139–140

Call-by-value, 138–139, 140
call( ), 930, 952

Callable interface, 907, 929–932, 952

CallSite class, 525
cancel( ), 629, 630, 951, 952
canRead( ), 518
canUse( ), 518
Canvas class
   AWT, 802, 805, 880
   JavaFX, 1109–1113
capacity( ), 459, 594, 718
capacityIncrement Vector data member, 594
Card layouts, 861–864
CardLayout class, 802, 861–864
CaretEvent class, 1031–1032
Case sensitivity and Java, 25, 27, 34, 190
case statement, 86–91
Casts, 50–52, 336, 339, 340, 342
   and casting one instance of a generic class into another, 368
   and erasure, 339, 371
   using instanceof with, 323–325
catch clause(s), 217, 218, 220–224, 226, 227–228, 236
   displaying exception description within, 222
   and the more precise (final) rethrow feature, 235, 236
   multi-catch feature of, 235–236
   using multiple, 222–223
   and nested try statements, 221, 224
CGI (Common Gateway Interface), 11, 1201–1202
changed( ), 1129, 1151
ChangeListener interface, 1128–1129
Channel interface, 720
Channel(s), NIO, 718, 720–721. See also NIO and channel-based I/O
char data type, 37, 41–42, 44, 68, 441
   and arithmetic operators, 63
   and automatic type conversion, 50
   and automatic type promotion, 52
Character class, 277, 467, 482–485
   and autoboxing/unboxing, 282–283
   methods, table of various, 482–283
   support for 32-bit Unicode, 484–485
Character(s), 37, 41–42
   basic multilingual plane (BMP), 484
changing case of, 455–456, 482, 483
classes (regular expressions), 983, 987
code point, 484
escape sequences, 45, 46
extraction from String objects, 445–446
formatting an individual, 635
literals, 45
supplemental, 484
Character.Subset class, 484
Character.UnicodeBlock class, 484
characteristics( ), 557, 558
CharArrayReader class, 308, 702–703
CharArrayWriter class, 308, 703–704
charAt( ), 155, 445, 460, 522
CharBuffer class, 719
CharSequence interface, 439, 456, 461, 522, 982
methods defined by, table of, 522
Charsets, 442, 722
carValue( ), 277, 482
Check boxes
  AWT, 830, 837–839
    as event sources, 773, 777, 782, 838, 1104, 1132, 1135
    indeterminate state of, enabling the, 1132, 1135
  JavaFX, 1132–1136
  Swing, 1038–1039
    and Swing menus, 1071, 1072–1073
Checkbox class
  AWT, 802, 837–839
  JavaFX, 1132, 1135
CheckboxGroup class, 802, 839–841
CheckboxMenuItem class, 802, 869, 870
checked… methods, 581–582, 585
checkedCollection( ), 581, 585
checkedList( ), 581, 585
checkedMap( ), 581, 585
checkedSet( ), 582, 585
CheckMenuItem class, 1162, 1173
Choice class, 802, 841–844
Choice controls, 782, 830, 841–847
  as event source, 773, 777, 782
ChoiceBox control, 1144
  methods, table of some, 502–503
.class file, 114, 190, 191
.class filename extension, 26
class keyword, 26, 111
CLASS retention policy, 285–286
Class(es), 26–27, 111–130
  abstract, 183–186, 187, 202
  access levels of, 192–193
  adapter, 790, 794–796
  anonymous, 17. See also Inner classes
  character, regular expression, 983, 987
  and code, 25, 111, 192
  in collections, storing user-defined, 558–560
  constructor. See Constructor
  controlling access to. See Access control
  as a data type, 111, 113, 115, 116, 117, 128
  definition of the term, 21
  encapsulation achieved through, 21, 128
  final, 187
  general form of, 111–112
  generic. See Generic class
  hierarchy, 22, 173–176, 198
  inner. See Inner classes
  instance of a, 21, 111, 113, 116
  and interfaces, 189, 198, 200–203, 359
  JShell to experiment with, using, 1250
  libraries, 25, 36
  literal, 288, 425
  member. See Member, class
  name and source file name, 25, 26
  nested, 151–153
  packages as containers for, 189, 192, 196
path, 418
public, 193
scope defined by a, 48
and state information, 210, 213
synthetic, 1246, 1248, 1249, 1250
type for bounded types, using a, 345–347
value-based, 614
ClassCastException, 230, 532, 533, 536, 538, 540, 561, 564, 565, 573, 585, 587, 589, 590
ClassDefinition class, 525
ClassFileTransformer interface, 525
ClassLoader class, 505
classModifiers( ), 993
ClassNotFoundException, 231, 713
CLASSPATH, 190, 191, 996
–classpath option, 191
ClassValue class, 522
clear( ), 531, 532, 562, 601, 611, 619, 718, 1156
Client/server model, 8–9, 11, 749
and sockets, 753–756
clone( ), 187, 499–501, 521, 594, 601, 611, 617, 619, 623, 1216
Cloneable interface, 499–501
CloneNotSupportedException, 231
Cloning
and enumerations, 521
potential dangers of, 500, 501
within a finally block, calling, 316–319, 677
Closeable interface, 314, 320, 653, 676, 679, 682, 693, 696, 698, 699, 700, 707, 720
Closures, 379
COBOL, 4
Code blocks, 30, 32–33, 47, 84–85
and the break statement, 106–108
and scopes, 47, 48–49
static, 147
synchronized, 253–255, 954
Code point, definition of, 484
Code
  snippet, 1245, 1247, 1248, 1250, 1253
  unreachable, 110, 223
codePointAt( ), 457, 464, 485, 486
codePointBefore( ), 457, 464, 486
codePointCount( ), 457, 464
collect( ), 957, 972–975
Collection interface, 530–533, 538, 543, 561, 959, 961, 965
  methods defined by, table of, 531–532
Collection-view, 529, 560, 561, 602
Collection(s), 335, 528–608
  algorithms, 529, 581–586, 592
  into arrays, converting, 532, 543–544
  and autoboxing, 544
  classes, 335, 540–551
  concurrent, 906, 933–934
  cycling through, 529, 551–558, 597
  dynamically typesafe view of a, 585
  and the for-each version of the for loop, 99, 103, 555–556, 597
Framework. See Collections Framework
  interfaces, 529, 530–540
  and iterators, 529, 533, 551–555, 556–558
  and legacy classes and interfaces, 592–608
  modifiable versus unmodifiable, 530
  and primitive types, 468, 544
random access to, 560
storing user-defined classes in, 558–560
and the stream API, 608, 955, 956, 959, 961, 974
stream API stream to obtain a, using a, 972–975
and synchronization, 540, 585, 592
and type safety, 585
when to use, 608
Collections class, 400, 529, 585, 592
  algorithms defined by, table of, 581–585
Collections Framework, 14, 99, 103, 279, 527–608, 934
advantages of generics as applied to the, 335
legacy classes and interfaces, 592–608
and method references, 400–402
overview, 528–529
Collector interface, 972
Collectors class, 972
Color class, AWT, 802, 807–808, 815–817
   constants to specify colors, list of, 808
   methods to manipulate colors, 815–816
Color class, JavaFX, 1111, 1156
Color, working with, 815–817
Combo box, JavaFX, 1141–1144
   enabling users to edit a, 1141, 1143–1144
Combo boxes, Swing, 1049–1051
ComboBox class, 1141
ComboBoxBase class, 1141
ComboBoxModel interface, 1050
Comment(s), 26, 27
   documentation, 34–35, 1227–1234
Common Gateway interface (CGI), 11, 1201–1202
commonPool( ), 941, 945
Compact profiles, 334
Comparable interface, 356, 359, 449, 522–523, 617, 673
Comparable<Path> interface, 722
Comparator interface, 401, 402, 530, 565, 570, 573, 961
comparator( ), 536, 550, 565
Comparators, 548, 549, 550, 570, 571, 572–580
   using a lambda expression with, 576–577, 580
compareAndSet( ), 907, 937
compareTo( ), 273–275, 449–450, 470, 471, 474, 475, 476, 478, 484, 487, 521, 522, 576, 617, 673
compareToIgnoreCase( ), 450
compareToIgnoreOptional( ), 492
compareUnsigned( ), 591
comparing( ), 574–575
comparingByKey( ), 565
comparingByValue( ), 565
comparingDouble( ), 575
comparingInt( ), 575
comparingLong( ), 575
Compilation unit, 25
compile( ), 982
Compiler
  ahead-of-time, 11
  Just-in-Time (JIT), 10, 14
Compiler class, 509
Compiler, Java, 25–26
  and main( ), 27
Component class, 771, 782, 802, 804–805, 807, 808, 809, 810, 822, 830, 855, 878, 880, 1014, 1015, 1018, 1020, 1024, 1025, 1061, 1257, 1258, 1259
ComponentAdapter class, 795
cOMPONENTADDEd( ), 784
ComponentEvent class, 773, 774–775, 776, 782
cOMPONENTHIDDEN( ), 784
ComponentListener interface, 783, 784, 795
cOMPONENTMOVED( ), 784
cOMPONENTREMOVED( ), 784
cOMPONENTRESIZED( ), 784
Components, AWT, 1011–1012, 1014
  lightweight versus heavyweight, 878
  and overriding paint( ), 878
Components and Java Beans, software, 1189
Components, Swing, 1014–1015, 1029–1057
  architecture, 1013–1014
  class names for, table of, 1014–1015
  and the Swing event dispatching thread, 1020
  heavyweight, 1015
  lightweight, 1012, 1029
  painting, 1024–1028
  and pluggable look and feel, 1012–1013, 1014
  and tabbed panes, 1042–1044
cOMPONENTSHOWN( ), 784
ComponentUI, 1014
compute() 940, 945, 949, 951, 954
concat() 453
Concurrency utilities 15, 905–954
  versus traditional multithreading and synchronization, 905, 954
Concurrent API, 905–906
  packages, 906–907
Concurrent collection classes, 906, 933–934
  list of, 933
Concurrent program, definition of the term, 905
ConcurrentHashMap class, 907, 933
ConcurrentLinkedDeque, 933
ConcurrentLinkedQueue class, 907, 933
ConcurrentSkipListMap class, 933
ConcurrentSkipListSet class, 933
Condition class, 935
connect() 754
Console class, 708–710
  methods, table of, 709
Console I/O, 28, 95, 305, 309–313, 708–710
console() 495, 709
const keyword, 36
Constants, 34
  using an interface to define shared, 206–208
Constructor class, 287, 290, 291, 526, 990
Constructor reference, 402–406
  for an array, 406
  to generic classes, 403–406
Constructor(s), 115, 123–126
  in class hierarchy, order of execution of, 176–177
default, 115, 125
enumeration, 271–273
factory methods versus overloaded, 751
generic, 357
object parameters for, 137–138
overloading, 134–136
parameterized, 125–126
reference. See Constructor reference(s)
and super(), 169–172, 176, 333
this() and overloaded, 331–333
constructorModifiers(), 993
Consumer<T> predefined functional interface, 407, 523, 556, 664, 962, 977
Container class, 802, 805, 807, 830, 855, 857, 858, 1014, 1015, 1019, 1025, 1061, 1257
Container, JavaFX, 1096–1097
Container(s), Swing, 1014, 1015
lightweight versus heavyweight, 1015
panes, 1015–1016. See also Content pane
top-level, 1014, 1015
ContainerAdapter class, 795
ContainerEvent class, 773, 775
ContainerListener interface, 783, 784, 795
Containment hierarchy, 1014, 1015
contains(), 457, 531, 532, 546, 594, 601
containsAll(), 531, 532
Content pane, 1015, 1016, 1019–1020, 1028, 1042, 1045, 1053, 1056, 1062, 1067
adding a component to a, 1019–1020
default layout manager of a JFrame, 1019, 1022–1023
ContentDisplay enumeration, 1119–1120, 1123
Context switching, 237, 253, 266
rules for, 239
ContextMenu class, 1162–1163, 1175–1176, 1178
ContextMenuEvent class, 1178
CONTINUE, 746
continue statement, 108–109
Control class, 1097, 1102, 1105, 1160
Control statements. See Statements, control
Control(s), AWT, 829, 830–854
action events, using an anonymous inner class or lambda expression to handle, 836–837
adding, 830
definition of an, 829
removing, 830
responding to, 830–831
Control(s), JavaFX, 1097, 1102, 1104, 1115–1160, 1186
adding an image to a, 1115, 1118–1123
adding a tooltip to a, 1160
disabling, 1160
and effects and transforms, 1154–1160. See also Effects; Transforms and event handling, 1102–1109
text, 1144–1146
convert( ), 933
ConvolveOp built-in convolution filter, 901
Convolution filters, 893, 899, 901
Cookie class, 1212, 1214–1215, 1220, 1222
   methods, table of, 1216
CookieHandler class, 763
CookieManager class, 763
CookiePolicy interface, 763
Cookies, 763, 1214–1215
   example servlet using, 1220–1222
CookieStore interface, 763
copy( ), 724, 737
copyOf( ), 551, 552, 587–588
copyOfRange( ), 588
CopyOnWriteArrayList class, 907, 933
CopyOnWriteArraySet class, 933
cos( ), 40, 505
count( ), 957, 963, 980
countDown( ), 914–915
CountDownLatch class, 906, 908, 913–915
CountedCompleter class, 939
countStackFrames( ), 512
createImage( ), 880, 885, 886, 890
createLineBorder( ), 1028
CropImageFilter class, 890–892
Currency class, 631–632
   methods, table of, 631
currentThread( ), 241, 510
currentTimeMillis( ), 495, 497
CustomMenuItem class, 1162
CyclicBarrier class, 906, 908, 915–917, 920
Data types, 29. See also Type(s); Types, primitive
DatagramPacket class, 764, 765–766
  methods, list of some, 766
Datagrams, 750, 764–767
  server/client example, 766–767
DatagramSocket class, 721, 764–765, 767
DataInput interface, 696, 697, 698, 713
DataInputStream class, 307, 696, 668–698
DataOutput interface, 696, 698, 669, 711
DataOutputStream class, 307, 696–698
Date and time. See Time and date; Time and date API
Date class, 616–618, 998, 999
  methods, table of, 617
DateFormat class, 616, 626, 997–999, 1004
DateTimeFormatter class, 1003–1006
Deadlock, 260–261, 512, 1020
Decoder class, 662
Decrement operator (– –), 32, 63, 66–67
decrementAndGet( ), 907, 937
depthEquals( ), 588–589
depthHashCode( ), 591
depthToString( ), 591
default
  clause for annotation member, 292–293
  to declare a default interface method, using, 210
  statement, 86–87
DefaultMutableTreeNode class, 1052, 1053
defaults Properties instance variable, 603
DelayQueue class, 933
Delegation event model, 770–771
  and Beans, 1192
  and event listeners, 770, 771, 783–786
  and event sources, 770–771, 782–783
  and JavaFX, 1105
  and Swing, 1021
using, 786–794
delete operator, 127
delete( ), 462–463, 673, 724
deleteCharAt( ), 462–463
deleteOnExit( ), 673
delimiter( ), 656
Delimiters, 609–610
   Scanner class, 647, 655–656
@Deprecated built-in annotation, 295, 297
Deque interface, 530, 539–540, 545, 550
   methods, table of, 539–540
descendingIterator( ), 537, 539, 540
destroy( ), 488, 491, 512, 513
   and applets, 1235, 1257, 1259, 1260
   and servlets, 1202, 1205, 1207
Dialog boxes, 874–878
Dialog class, 802, 874
Dialog windows, 1091
Diamond operator (<>), 370–371
Dictionary class, 528, 592, 599–600
   abstract methods, table of, 599
digit( ), 484
Dimension class, 802, 806, 813
   reflection example using the, 990–991
Directories as File objects, 671, 673–674
   creating, 676
Directories and packages, file system, 190
Directory, listing the contents of a
   using list( ), 673–675
   using listFiles( ), 675–676
   using NIO, 742–745
Directory tree, obtaining a list of files in a, 746–748
DirectoryStream<Path> class, 742, 743
DirectoryStream.Filter interface, 744
DISCARD, 494
dispose( ), 874
distinct( ), 980
do-while loop, 92–95
Document interface, 1031
@Documented built-in annotation, 295, 296
doDelete( ), 1216, 1217
doGet( ), 1216, 1217, 1218
doHead( ), 1216, 1217
Domain name, 750, 751
Domain Naming Service (DNS), 750
doOptions( ), 1216, 1217
doPost( ), 1217, 1219
doPut( ), 1217
DosFileAttributes class, 726, 727, 742
DosFileAttributeView interface, 728
Dot operator (.), 81, 113, 119, 148, 172, 196, 213
doTrace( ), 1217
Double buffering, 882–885
Double class, 277, 278, 468–473, 480
   methods, table of, 471–472
double data type, 37, 40–41, 44
   and automatic type conversion, 50
   and automatic type promotion, 52–53
DoubleAccumulator class, 937
DoubleAdder class, 937
DoubleBinaryOperator functional interface, 590
DoubleBuffer class, 719
doubles( ), 628
DoubleStream interface, 958, 959
DoubleSummaryStatistics class, 662
doubleValue( ), 278, 345, 468, 470, 471, 474, 475, 476, 478
drawArc( ), 811
drawImage( ), 881, 883, 884
drawLine( ), 810, 1024
drawOval( ), 811
drawPolygon( ), 811–812
drawRect( ), 810–811, 1024
drawRoundRect( ), 811
drawString( ), 790, 807, 808, 825, 826, 1256
Duration class, 1007
Dynamic method
    dispatch, 180–183
    lookup, 201
    resolution, 198, 201, 202, 206

E
E (Math constant), 505
Early binding, 186
echoCharIsSet( ), 851
Eclipse IDE, 1202, 1203
Edit control, 850
Effect class, 1155
Effects, 1155–1156
    list of some built-in, 1155
    program demonstrating, 1157–1160
element( ), 538
elementAt( ), 594
elementCount Vector data member, 594
elementData Vector data member, 594
elements( ), 594, 599, 600, 601
ElementType enumeration, 296, 525
ElementType.FIELD, 301
ElementType.METHOD, 301
ElementType.TYPE_USE, 298, 301
else, 83–86
empty( ), 597, 598, 614, 616
EMPTY_LIST static variable, 585
EMPTY_MAP static variable, 585
EMPTY_SET static variable, 585
EmptyStackException, 597, 599
Encapsulation, 5, 20–21, 22, 24–25, 128, 169
    and access control, 143
    and scope rules, 48
Encoder class, 662
end( ), 982–983
endsWith( ), 448, 723
ensureCapacity( ), 459, 543, 594
entrySet( ), 561, 562, 565, 569, 602
denum, 268, 521, 551, 572
Enum class, 273, 521
  methods, table of, 521
denumerate( ), 510, 513, 516
Enumeration interface, 592–593, 595–597, 600, 609, 610, 692
Enumeration(s), 15, 267–276, 521
  = = relational operator and, 268, 244
  as a class type in Java, 267, 271–273
  constants, 267, 268, 269, 270, 271, 272, 273
  constructor, 271–273
  and JShell, 1251
  restrictions, 273
  values in switch statements, using, 268–270
  variable, declaring an, 268
EnumMap class, 568, 571
EnumSet class, 541, 551
  factory methods, table of, 552
Environment properties, list of, 498
  versus = =, 448–449
equalsIgnoreCase( ), 447
equalsIgnoreOptional( ), 492
Erasure, 339, 371–374
  and ambiguity errors, 373–374
  bridge methods and, 372–373
err, 308, 495. See also System.err
Error class, 218, 219, 227, 234, 708
Errors
  ambiguity, 373–374
  assertions to check for, using, 326–328
  autoboxing/unboxing and prevention of, 283–284
  automatic type promotions and compile-time, 52
compile-time versus run-time, 342
generics and prevention of, 340–342
raw types and run-time, 362
run-time, 13, 217, 323. See also Exception handling
unreachable code, 110, 223

Event
  bubbling, 1105
  change, 1128–1129, 1137, 1141, 1154
definition of an, 770
design patterns for a Java Bean, 1192
dispatch chain, 1105
dispatching thread and Swing, 1020, 1024, 1060
driven programs, 769, 1020
filter, 1105
listeners, 770–771, 783–786
loop with polling, 238, 255
model, delegation. See Delegation event model
multicasting and unicasting, 771, 1192
sources, 770–771, 782–783
timestamp, 773
Event class, 1105
Event handling, 769–799
  and adapter classes, 794–796
event classes for, 771–782
  and immediate and quick event processing, 771, 786, 808, 1024, 1106
  and inner classes, 153, 796–799, 836, 837
  and JavaFX, 1102, 1104–1109
  keyboard, 790–794
  and lambda expressions, 836–837, 1023–1024
  mouse, 785, 787–790
  and Swing, 772, 1012, 1021–1024
  See also Delegation event model
Event listener interfaces, 783–786
  and adapter classes, 794–796
table of commonly used, 783
EventHandler interface, 1105, 1108, 1109
EventListener interface, 662
EventListenerProxy class, 662
EventObject class, 662, 772, 1105
EventSetDescriptor class, 1192, 1194, 1196
Exception class, 218, 219, 231, 233, 234
Exception classes
  and generics, 377
  hierarchy of the built-in, 218–219
Exception handling, 13, 95, 104, 217–236, 316, 317–319
  block, general form of, 218
  and chained exceptions, 15, 234–235
  and creating custom exceptions, 231–233
  and the default exception handler, 219–220, 226
  and lambdas, 392–393
  and the more precise (final) rethrow feature, 235, 236
  multi-catch, 235–236
  and suppressed exceptions, 232, 322
  and uncaught exceptions, 219–220, 524
Exception Site List, 1237, 1239, 1242, 1243
Exception(s)
  definition of the term, 217
  and JShell, 1253
Exceptions, built-in, 230–231
  checked, table of, 231
  run-time, constructors for, 227
  unchecked, table of, 230
Exceptions, I/O, 677
exchange( ), 917, 918, 919
Exchanger class, 906, 908, 917–919
exec( ), 485, 489, 491–492
execute( ), 927, 941, 951
Execution point, 520
Executor interface, 907, 927
Executors, 906, 907
  using, 927, 929
Executors class, 907, 927
ExecutorService interface, 907, 927, 928, 930
exists( ), 671, 724, 740
exit(). See System.exit()
exitValue(), 488, 491
exports keyword, 35, 410
exports statement, 410, 414, 416
  and qualified export, 418–419
Expression lambda, 385. See also Lambda expression(s)
Expressions
  and autoboxing/unboxing, 281–282
  automatic type promotion in, 52–53
  JShell to evaluate, using, 1251–1252
  regular. See Regular expressions
extends, 163, 165, 208, 345, 350, 363
  and bounded wildcard arguments, 351, 354
Externalizable interface, 711, 1193

F
false, 36, 42, 43, 45, 77, 78, 79, 125
FALSE, 485
FAT file system, 726, 728, 742
Field class, 287, 290, 291, 526, 990
Field, final, 148–149
fieldModifiers(), 993
fields array (Calendar class), 618
File attribute(s)
  File to access, using, 671–676, 740
  interfaces, 726–728
  NIO to access, using, 727–728, 740–742
  view interfaces, 728
File class, 647, 671–676, 679, 683, 694, 698, 700, 708, 740
  instance into a Path instance, converting a, 673, 722, 740
  methods, 671–676, 680
File system directories and packages, 190
file(), 494
File(s)
  to a buffer, map a, 721, 732–733, 736–737
  close() to close a, using, 314, 316–318, 319, 322, 684
I/O, 313–322, 671–676. See also NIO; NIO and channel-based I/O
path to a, obtaining a, 722, 725–726, 729
pointer, 698
source, 25–26, 284
system, accessing the, 728
try-with-resources to automatically close a, using, 314, 319–322, 684
FileChannel class, 721, 729, 732, 733, 734, 736
FileDialog class, 802
FileFilter interface, 676
FileInputStream class, 307, 313–314, 679–682, 721
FilenameFilter interface, 674–675, 676
FileNotFoundException, 314, 317, 677, 679, 683, 700
FileOutputStream class, 307, 313–314, 318, 682–685, 721
FileReader class, 308, 647, 700
Files class, 671, 721, 723–725, 727, 728, 737, 738, 740, 741, 742, 746
methods, table of a sampling of, 724–725
FileStore class, 728
FileSystem class, 728
FileSystems class, 728
FileVisitor interface, 746–747
FileVisitResult enumeration, 746
FileWriter class, 308, 701–702
fill( )
   algorithm defined by Collections, 582
   Arrays method, 589
fillArc( ), 811
fillOval( ), 811, 1110
fillPolygon( ), 811–812
fillRect( ), 810–811, 1110
fillRoundRect( ), 811
fillText( ), 1110
filter( ), 614, 616, 957, 958, 962–963, 970
FilteredImageSource class, 885, 890
FilterInputStream class, 307, 688, 696
FilterOutputStream class, 307, 688, 696
FilterReader class, 308
FilterWriter class, 308
final, 148–149, 235, 236
    to prevent class inheritance, 187
    to prevent method overriding, 186
finalize( ), 187, 499
finally block, 217, 218, 228–229, 316–317, 677
find( ), 725, 982, 984–985
findAll( ), 657
findInLine( ), 656–657
findWithinHorizon( ), 657
Finger protocol, 757
fire( ), 1126, 1128, 1129, 1165
first( ), 536, 862
firstElement( ), 594
firstKey( ), 565
flatMap( ), 614, 616, 972
flatMapToDouble( ), 972
flatMapToInt( ), 972
flatMapToLong( ), 972
flip( ), 611, 718, 735
Float class, 277, 278, 468–471, 472–473, 480
    methods, table of, 470–471
float data type, 37, 40, 44
    and type promotion, 52–53
Floating-point(s), 37, 40–41
    literals, 44–45
    strictfp and, 325
FloatBuffer class, 719
floatValue( ), 278, 468, 470, 471, 474, 475, 476, 478
Flow class, 907
Flow subsystem to control data flow, 907
Flow.Processor interface, 907
Flow.Publisher interface, 907
Flow.Subscriber interface, 907
Flow.Subscription interface, 907
FlowLayout class, 803, 832, 854, 855–856, 1022–1023
FlowPane class, 1097, 1100–1101, 1108–1109, 1177
flush( ), 633, 676, 681, 690, 700, 709, 711, 712
Flushable interface, 676, 679, 682, 693, 696, 700, 707, 708
FocusAdapter class, 795
FocusEvent class, 773, 775–776
FocusEvent.Cause enumeration, 776
focusGained( ), 784
FocusListener interface, 783, 784, 795
focusLost( ), 784
Font class, AWT, 803, 820, 821, 822, 824
   methods, table of some, 820
Font class, JavaFX, 1110
Font(s), 819–825
   creating and selecting, 822–824
determining available, 821–822
information, obtaining, 824–825
metrics to manage text output, using, 825–828
terminology used to describe, 825
FontMetrics class, 803, 825–828
   methods, table of some, 826
for loop, 31–32, 42, 95–104
   enhanced. See For-each version of the for loop variations, 98–99
For-each version of the for loop, 15, 95, 99–103
   and arrays, 99–103
   and the break statement, 100–101
   and collections, 99, 103, 530, 555–556
general form, 99
   and the Iterable interface, 523, 530, 555
   and maps, 560
forceTermination( ), 927
forDigit( ), 484
forEach( ), 523, 553, 957, 958, 962, 967
forEachOrdered( ), 967
forEachRemaining( ), 552, 553, 556–558, 978
Fork/Join Framework, 16–17, 239, 266, 663, 905–906, 907, 927, 938–954
   advantages to using the, 938, 954
classes, main, 938–942
tips for using the, 954
Fork/Join Framework divide-and-conquer strategy, \textit{940, 942–945, 954}, and the sequential processing threshold interaction with the level of parallelism, \textit{945–948}

Fork/Join Framework tasks, \textit{939}
- asynchronous execution of, \textit{951}
- cancelling, \textit{951}
- completion status of, \textit{952}
- and the parallelism level, \textit{941, 954}
- restarting, \textit{952}
- starting, \textit{941, 951}
- and subtasks, \textit{941, 942}
- tags, \textit{953}
  - that do not return a result, \textit{940, 944, 948}
  - that return a result, \textit{940, 948–951}

\texttt{fork( )}, \textit{939, 941, 945, 949, 950, 952}

ForkJoinPool class, \textit{907, 927, 938, 939, 940–942, 943, 944, 945, 948, 951, 953–954}
- common pool, \textit{940, 941, 945, 948, 954}
- and work stealing, \textit{941, 953}

ForkJoinTask class, \textit{907, 938, 939, 940, 941, 944, 945, 951, 952–953, 954}

ForkJoinTask\langle T\rangle class, \textit{942}

Format flags, \textit{642–644}

Format specifiers (conversions), \textit{632, 633–646}
- argument index with, using an, \textit{645–646}
- and format flags, \textit{642–644}
- and specifying minimum field width, \textit{639–640}
- and specifying precision, \textit{641}
- suffixes for the time and date, table of, \textit{637–638}
- table of, \textit{634}
- uppercase versions of, \textit{644–645}

\texttt{format( )}, \textit{457, 633–635, 645, 695, 696, 708, 709, 998, 1003}

FormatStyle enumeration, \textit{1004}

Formattable interface, \textit{662}

FormattableFlags class, \textit{662}

Formatted input, using Scanner to read, \textit{647–657}

Formatter class, \textit{632–647, 694, 695}
- closing an instance of the, \textit{646–647}
- constructors, \textit{632–633}
methods, table of, 633

See also Format specifiers

forName( ), 502, 990

FORTRAN, 4, 5

Forward reference, 1249

Frame class, 782, 783, 787, 789, 803, 804, 805, 807, 856

Frame window(s), 805–810
  and creating a Frame-based application, 809–810
  default layout manager for, 856
  methods used to work with a, 806–808
  requesting repainting of a, 808–809

Frank, Ed, 6

freeMemory( ), 488, 489, 490

from( ), 494, 617, 622

FTP (File Transfer Protocol), 750, 757

Function<T,R> predefined functional interface, 407, 574, 644, 968

Functional interfaces, 17, 297, 379, 380, 381–382, 384, 837
  and their abstract methods, table of, 664–666
  generic, 387–389
  and lambda expressions passed as arguments, 389–391
  predefined, 406–407
  and public Object methods, 380

@FunctionalInterface built-in annotation, 295, 297

Future interface, 907, 930–932

FXCollections class, 1136, 1141

FXXML, 1096

G

Garbage collection, 13, 127, 141, 487–488, 525, 1202

gc( ), 488, 489, 490

Generic class
  and casting, 368
  definition of the term, 336
  example program with one type parameter, 336–340
  example program with two type parameters, 343–344
  general form of a, 344
hierarchies, 362–370
and instanceof, 366–368
overriding methods in a, 369–370
and raw types, 360–362
and type inference, 370–371
Generic constructors, 357
Generic interfaces, 336, 358–360
and classes, 359
Generic method, 336, 348, 354–357, 375
Generics, 15, 279, 335–377
and annotations, 304
and ambiguity errors, 373–374
and arrays, 375–377
and casts, 336, 339, 340, 342
and the Collections Framework, 335
and compatibility with pre-generics code, 360–362, 371
and exception classes, 377
restrictions when using, 375–377
type checking and safety, 339, 340–342, 361, 377
GenericServlet class, 1205, 1207, 1210, 1215
get( ), 533, 534, 546, 561, 562, 568, 599, 600, 601, 611, 614, 615, 619, 666, 725–726, 729, 731, 733, 763, 930, 932–933, 937, 961, 962, 975
and buffers, 719, 720, 731
getActionCommand( ), 773, 833, 845, 1034, 1040, 1068
getActiveThreadCount( ), 953
getAddListenerMethod( ), 1196
getAddress( ), 752, 766
getAdjustable( ), 774
getAdjustmentType( ), 774, 848
getAlignment( ), 831
getAllByName( ), 751, 752
getAllFonts( ), 821
getAndSet( ), 907, 937
getAnnotation( ), 287, 291, 302–303, 502, 517, 519
getAnnotations( ), 290–291, 502, 517
getAnnotationsByType( ), 291, 303, 502, 517
getArrivedParties( ), 927
getAsDouble( ), 616
getAscent( ), 826, 827
getAsInt( ), 616
getAsLong( ), 616
getAttribute( ), 1208, 1209, 1215, 1222
getAttributeNames( ), 1215, 1222
getAvailableFontFamilyNames( ), 821
setBackground( ), 808
getBeanInfo( ), 1196
getBlue( ), 816
getButton(), 780
getByAddress( ), 752
getByNullReference( ), 751, 752
getBytes( ), 446, 683
getCause( ), 232, 234–235, 776
getChannel( ), 721
getChars( ), 445–446, 460, 701
getChild( ), 775
getChildren( ), 1102–1103, 1150, 1151
getClass( ), 187, 188, 286–287, 338, 499, 501, 504, 992
getClassLoader( ), 519
getClickCount( ), 779
getColor( ), 816
getCommonPoolParallelism( ), 948
getComponent( ), 775, 1074, 1075, 1076
getConstructor( ), 287, 502
getConstructors( ), 502, 990
getContainer( ), 775
getContentPane( ), 1019–1020
getContents( ), 660
getContentType( ), 759
getCookies( ), 1213, 1221
getDate( ), 759
generateDateString( ), 997–998
getDateTimeInstance( ), 999
getDeclaredAnnotation( ), 291, 517
getDeclaredAnnotations( ), 291, 502, 517, 519
getDeclaredAnnotationsByType( ), 291, 303, 502, 518
getDeclaredMethods( ), 503, 992
getDefault( ), 623, 626
getDescent( ), 826, 827
getDescriptor( ), 519
getDirectionality( ), 484
getDisplayCountry( ), 625
getDisplayLanguage( ), 625
getDisplayName( ), 625, 631
getEchoChar( ), 851
getEventSetDescriptors( ), 1192, 1199
GetField inner class, 713–714
getField( ), 287, 503
getFields( ), 503, 990
getAddress( ), 728
getFirst( ), 539, 545
g.getFont( ), 820, 824, 826, 1110
getForeground( ), 808
getForkJoinTaskTag( ), 953
default( ), 623, 626
default( ), 826, 827
default( ), 519
default( ), 484
default( ), 625
default( ), 625, 631
default( ), 851
default( ), 1192, 1199
GetField inner class, 713–714
default( ), 287, 503
default( ), 503, 990
default( ), 728
default( ), 539, 545
default( ), 820, 824, 826, 1110
default( ), 808
default( ), 953
default( ), 673
default( ), 808, 882
default( ), 1110
default( ), 816
default( ), 759
default( ), 759, 763
default( ), 826, 827, 1026
default( ), 753
default( ), 753
default( ), 1006
default( ), 1148
default( ), 1030
default( ) AWTEvent class method, 772
default( ), 754, 765
default( ), 1208
default( ), 1208
default( ), 488, 492, 754, 759
default( ), 814, 858, 1025–1026
getInstance(), 619, 621, 631
getISOCountries(), 626
getItem(), 777, 842, 845, 870, 1036, 1038
getItemCount(), 842, 845
getItems(), 1164, 1169, 1179
g GettingItemSelectable(), 778, 845
getKey(), 567, 569
getKeyChar(), 778
getKeyCode(), 778
getKeyStroke(), 1069
getLabel(), 833, 837, 869–870
getLast(), 539, 545
getLayer(), 519
getLeading(), 826, 827
getListenerType(), 1196
getLocalGraphicsEnvironment(), 821
getLocalHost(), 751, 752
getLocalPort(), 754, 765
gLocationOnScreen(), 780
getLogger(), 495
g MAXIMUM(), 848
getMenuComponentCount(), 1063
getMenuComponents(), 1063
g getMenuCount(), 1061
g getMenus(), 1163
g getMessage(), 227, 232
g getMethod(), 287, 289, 503, 1196, 1213
g getMethodDescriptors(), 1192
g getMethods(), 503, 990
g getMinimum(), 848
g getMinimumSize(), 855
g getModifiers(), 773, 777, 992
g getModifiersEx(), 777
g getModule(), 502, 503, 519
g getMonth(), 1006
g N() getter method design pattern, 1190, 1191
getName(), 240, 242, 338, 503, 511, 513, 518, 519, 671, 722, 723, 740, 820, 992,
getSelectedCheckbox( ), 840
getSelectedIndex( ), 842, 844, 1047
getSelectedIndexes( ), 845
getSelectedItem( ), 842, 844, 1050
getSelectedItems( ), 845, 1140
getSelectedText( ), 850–851, 853
getSelectedToggle( ), 1132
getSelectedValue( ), 1047
getSelectionModel( ), 1137, 1150
getServletConfig( ), 1207
getServletContext( ), 1208
getServletInfo( ), 1207
getServletName( ), 1208
getSession( ), 1213, 1222
getSize( ), 806, 813, 820
getSource( ), 772, 835, 1040, 1105
getStackTrace( ), 232, 511, 520
getState( ), 264–265, 511, 837, 870
getStateChange( ), 778, 845
getSubElements( ), 1062
getSupersclass( ), 503, 504
getSuppressed( ), 232, 322
getSurplusQueuedTaskCount( ), 952–953
getTarget( ), 1170
text( ), 831, 850, 853, 1030, 1032, 1033, 1038, 1144, 1170
timeInstance( ), 998–999
transforms( ), 1156
getUnarrivedParties( ), 927
totalSpace( ), 673
usableSpace( ), 673
getValue( ), 567, 569, 774, 847, 1080–1081, 1141–1142, 1151, 1216, 1221
getVvalue( ), 1148
getWheelRotation( ), 780–781
getWhen( ), 773
getWidth( ), 1026
getWindow( ), 782
gewriter( ), 1205, 1209
getX( ), 779, 1074, 1076
getXOnScreen( ), 780, 1074, 1076
getY( ), 779
getYear( ), 1006
getYOnScreen( ), 780
GIF image format, 879–880
Glass pane, 1015, 1016
Glassfish, 1202
Glob, 744
Glow class, 1155
  program demonstrating, 1157–1160
Gosling, James, 6
goto keyword, 35
Goto statement, using labeled break as form of, 106–108
grabPixels( ), 887, 888
Graphical User Interface. See GUI (Graphical User Interface)
Graphics
  and JavaFX retained mode, 1109
  context, 790, 807, 809, 810
  sizing, 813–815
Graphics class, 790, 803, 807, 810, 816, 824, 881, 882
  drawing methods, 810–813
Graphics2D class, 810
GraphicsContext class, 1109–1113
GraphicsEnvironment class, 803, 821
Greedy behavior (regular expression pattern matching), 986, 987
GregorianCalendar class, 618, 621–623, 626, 1001
Grid bag layouts, 864–869
GridBagConstraints class, 803, 864–866
  constraint fields, table of, 865
GridBagLayout class, 803, 865, 866, 869
gridheight constraint field, 865, 866
GridLayout class, 803, 860–861
GridPane class, 1097
gridwidth constraint field, 865, 866
Group class, 1097
group( ) Matcher class method, 982
GIU (Graphical User Interface), 305, 801, 829
   approaches to the, 1095
effects and transforms to customize the look of a JavaFX, using, 1154–1160
   frameworks, Java’s three, 786–787
   programs, handling events generated by, 769–799, 808
GZIP file format, 667

H
handle( ), 1105, 1108, 1170
hasCharacteristics( ), 557, 558
Hash code, 546, 600
Hash table, 546, 600
hashCode( ), 187, 285, 470, 471, 474, 475, 476, 478, 484, 487, 499, 518, 520, 521,
   531, 562, 567, 591, 600, 611, 614, 617, 820
Hashing, 546, 547
HashMap class, 568–570, 571, 572, 600
HashSet class, 541, 546–547, 568, 959
   from a stream API stream, obtaining a, 975
Hashtable class, 541, 591, 600–603
   and iterators, 602–603
   legacy methods, table of, 601
hasMoreElements( ), 593, 610
hasMoreTokens( ), 610
hasNext( ), 552, 553, 556, 976, 977
hasNextX( ) Scanner methods, 648, 651
   table of, 649
HBox layout, 1186
Headers, 759
HeadlessException, 806, 831
headMap( ), 564, 565, 566
headSet( ), 536, 537
Hexadecimals, 43, 45
   as character values, 45
   and string literals, 46
Hierarchical abstraction and classification, 20
   and inheritance, 21, 163
High surrogate char, 485
Histogram, 888–889
Hoare, C.A.R., 240
Holzmann, Gerard J., 886
HotSpot technology, 10
HSB (hue-saturation-brightness) color model, 815
HSBtoRGB( ), 816
HTML (Hypertext Markup Language), 1201, 1205
  file for an applet, 1256
  file for a JavaFX application, 1101, 1102
  and javadoc, 1227, 1228, 1233
HTMLEditor, 1146
HTTP, 750, 757
  GET requests, handling, 1217–1218
  and HttpURLConnection class, 761
  port, 750
  POST requests, handling, 1217, 1219–1220
  requests, 1201, 1202, 1212–1213, 1217
  response, 1201, 1202, 1205, 1212–1213, 1214
  and URLConnection class, 759
HTTP session
  stateful, 763
  tracking, 1222–1223
HttpCookie class, 763
HttpServlet class, 1212, 1215, 1217
  methods, table of, 1216–1217
HttpServletResponse interface, 1212, 1218, 1219, 1222
  methods, table of several, 1213
HttpServletResponse interface, 1212–1213, 1214
  methods, table of, 1214
HttpSession interface, 1212, 1213, 1222
  methods, table of several, 1215
HttpURLConnection class, 761–763
  methods, sampling of, 761
Icon interface, 1030
Icons
   Swing button, 1033, 1077
   Swing label, 1030
Identifiers, 26, 34, 36, 46, 47
IdentityHashMap class, 568, 572
if statement, 30–31, 32, 42, 43, 83–86
   Boolean object used to control the, 283
   boolean variable used to control the, 84, 283
   nested, 85
   and recursive methods, 142
   switch statement versus, 90–91
if-else-if ladder, 85–86
IllegalAccessException, 227, 231
IllegalArgumentException, 230, 532, 533, 536, 538, 540, 551, 561, 564, 565, 588
IllegalStateException, 230, 532, 538, 540, 982, 983, 1213
Image class
   AWT, 803, 879, 880, 881, 882, 885, 887
   JavaFX, 1115–1117
ImageConsumer interface, 887–889, 890
ImageFilter class, 890, 892
ImageIcon class, 1029, 1030, 1078
ImageIO class, 880
Image observer, 881
ImageObserver interface, 881
ImageProducer interface, 880, 885, 887, 890
Images (AWT), 879–904
   creating, loading, displaying, 880–882
   double buffering and, 882–885
   file formats for web, 879–880
   filters for, 890–904
   stream model for, 890
Imaging, 879
ImageView class, 1115–1117, 1118, 1120
implements clause, 200
   and generic interfaces, 359, 360
import statement, 196–197, 1253
and static import, 329–331
in, 308, 492, 495, 647, 708. See also System.in
Increment operator (++), 32, 63, 66–68
indexOf(), 450–452, 464–465, 533, 534, 594
IndexOutOfBoundsException, 230, 533
InetAddress class, 751–753, 764
InetAddress class, 751–753, 764
InetSocketAddress class, 765
infinity (IEEE floating-point specification value), 472
inForkJoinPool(), 952
INHERIT, 494
InheritableThreadLocal class, 517
Inheritance, 5, 20, 21–22, 24–25, 144, 146, 163–187
and annotations, 304
and enumerations, 273
final and, 186–187
and interfaces, 189, 198, 208–209, 212–213, 214
multilevel, 173–176
and multiple superclasses, 165, 189
@Inherited built-in annotation, 295, 296
init() and applets, 1235, 1257, 1259, 1260, 1262
and JavaFX, 1097, 1098, 1100, 1102
and servlets, 1202, 1205, 1207
initCause(), 232, 234
Inline method calls, 186
Inner classes, 151–153, 796–799
anonymous, 153, 798–799, 836, 837, 926, 1023, 1040, 1061, 1075–1076, 1105, 1109, 1162, 1169
InnerShadow class, 1155–1156
program demonstrating, 1157–1160
InputEvent class, 773, 776–777, 778, 779, 1069
InputMismatchException, 651
methods, table of, 680
objects, concatenating, 692
InputStreamReader class, 308, 309
insert( ), 461–462, 853, 1062
insertSeparator( ), 1062
Insets
  definition of the term, 813–814
  example program, 858–859
Insets class, 803, 814, 858–859, 1025
Instance of a class, 21, 111, 113, 116. See also Object(s)
Instance variables
  accessing, 113, 118, 119, 122
  default values of, 125
  definition of the term, 21, 112
  hiding, 127
  and interfaces, 210
  static, 147–148
  transient, 323
    as unique to their object, 113, 114–115
    using super to access hidden, 172–173
instanceof operator, 63, 323–325, 560
  and generic classes, 366–368
Instant class, 617, 1007
Instrumentation interface, 525
int, 29, 37, 38, 39
  and automatic type conversion, 50
  and automatic type promotion, 52–53, 71–72, 74–75
  and integer literals, 43
IntBuffer class, 719
Integer class, 277, 278, 279, 282, 467, 473, 480–481, 961
  constructors, 278
  methods, table of, 476–478
Integer(s), 37, 38–40, 68–69
  literals, 43–44, 50
interface keyword, 189, 198
  and annotations, 285
Interface methods
default, 17, 18, 199, 209–213, 379, 381
extension, 209
private, 18, 199, 214–215
static, 199, 213–214
traditional, 198, 200, 381
Interface(s), 189, 198–215
  functional. See Functional interfaces
general form of, 199
generic. See Generic interfaces
implementing, 200–202
inheritance hierarchy, 198
inheritance of, 208–209, 213
and JShell, 1250–1251
member, 202
methods. See Interface methods
nested, 202–203
reference variables, 200–202, 206
and state information, 210, 213
types for bounded types, using, 347
variables, 199, 206–208
interfaceModifiers( ), 993
Internet, 3, 6, 7, 8, 9, 14, 18, 749
  addresses, obtaining, 752–753
  addressing scheme, 750
  and portability, 7, 8, 9–10
  and security, 8, 9
Internet Engineering Task Force (IETF) BCP 47, 626
Internet of Things (IoT), 409
Internet Protocol (IP)
  addresses, 750
  definition of the term, 749
InterNIC, 754, 756
InterruptedException, 231, 241–242, 888
Introspection, 1190–1193, 1196, 1198–1199
Introspector class, 1195, 1196
ints( ), 628
IntStream interface, 958, 959, 971
IntSummaryStatistics class, 662
intValue( ), 278, 279, 468, 470, 471, 474, 475, 476, 479
InvalidPathException, 725
invoke( ), 939, 941, 945, 951, 953
invokeAll( ), 939, 945, 949, 952
invokeAndWait( ), 1020, 1021, 1262
invokeLater( ), 1020, 1262
I/O, 28, 305–322, 669–716
channel-based, 15, 306, 717. See also NIO; NIO and channel-based I/O
classes, list of, 670
console, 28, 95, 305, 309–313, 708–710
error handling, 316–319
exceptions, 677
file, 313–322, 671–676
formatted. See I/O, formatted
interfaces, list of, 670
and Java’s GUI frameworks, 305
new. See NIO
redirection, 494
streams. See Streams, I/O
I/O, formatted, 15
format specifiers. See Format specifiers
using Formatter, 632–647. See also Formatter class
using printf( ), 157, 694–696
using Scanner, 647–657. See also Scanner class
io package. See java.io package
IOError, 709
IOException, 95, 309, 314, 317, 318, 677, 679, 680, 684, 691, 699, 700, 701, 707,
712, 713, 723, 742, 746, 754, 758, 764
ipadx constraint field, 865, 866
ipady constraint field, 865, 866
IPv4 (Internet Protocol, version 4), 750, 751, 752, 753
IPv6 (Internet Protocol, version 6), 750, 751, 752, 753
isAbsolute( ), 672, 723
isAlive( ), 240, 248–250, 486, 488, 511
isAltDown( ), 777
isAltGraphDown( ), 777
isAnnotationPresent( ), 291, 293, 518
isBound( ), 754, 765, 1196
isCancelled( ), 951, 952
isClosed( ), 754
isCompletedAbnormally( ), 952
isCompletedNormally( ), 952
isConnected( ), 754, 765
isConstrained( ), 1196
isControlDown( ), 777
isDigit( ), 482, 483, 485
isDirectory( ), 673–674, 724, 727
isEditable( ), 851, 853
isEmpty( ), 457, 531, 532, 562, 595, 599, 600, 601, 612
isEnabled( ), 869, 1081
isExecutable( ), 724, 740
isExported( ), 519
isFile( ), 672
isHidden( ), 673, 724, 726, 728, 740
isIndeterminate( ), 1135
isInfinite( ), 470, 472–473
isLeapYear( ), 622
isLetter( ), 482, 483, 485
isLightweight( ), 878
isLowercase( ), 482, 483
isMetaDown( ), 777
isMulticastAddress( ), 753
isNamed( ), 519
isNaN( ), 470, 472–473
ISO-Latin-1 character set, 41, 45
isOpen( ), 519
isPopupTrigger( ), 779, 1074, 1076
isPresent( ), 615, 961
isPropertyName( ), 1191
isPublic( ), 992
isQuiescent( ), 953
isReadable( ), 724, 740
isSelected( ), 1036, 1038, 1040, 1062, 1124, 1125, 1135
isSet array (Calendar class), 618
isShiftDown(), 777
isShutdown(), 954
isTemporary(), 776
isTerminated(), 954
isTimeSet (Calendar class instance variable), 618
isUppercase(), 482, 483
isWhitespace(), 482, 483
isWritable(), 724, 728, 740
ItemEvent class, 773, 777–778, 838, 842, 845, 870, 1036, 1038
ItemListner interface, 783, 784, 837, 838, 842, 870, 1036, 1038
ItemSelectable interface, 778
itemStateChanged(), 784, 838, 842, 1036, 1038
Iterable interface, 457, 523, 530, 555, 560, 593
Iterable<Path> interface, 722, 743
Iteration statements, 83, 91–102
Iterator interface, 529, 530, 551, 553–555, 556, 592, 593, 976, 977
methods, table of, 552
iterator(), 523, 531, 533, 553, 743, 956, 976
Iterator(s), 529, 533, 551–555, 556–558
and maps, 560
obtaining an, 553
and primitive types, 529
and PriorityQueue, 550
and stream API streams, 976–979
and synchronized collections, 585

J
J2SE 5, new features of, 15
JApplet class, 1015, 1235, 1255, 1260, 1262
JAR files. See Java Archive (JAR) files
jar tool, 435, 1236, 1240
jarsigner command-line tool, 1237, 1241
Java
applications and Java Web Start, web-based deployment of, 1235
and C, 3, 5, 7, 12
and C++, 3, 7–8, 12
and C#, 8
design features (buzzwords), 12–14
history of, 3, 6–8, 14–18
and the Internet, 3, 6, 7–10, 14, 18, 749
as an interpreted language, 10, 13
keywords. See Keywords
look and feels, 1013
as a strongly typed language, 13, 37, 43
versions of, 14–18
and the World Wide Web, 7, 12
Java Archive (JAR) files, 436, 663, 1098, 1102
and Java Web Start, 1235, 1236–1237, 1238, 1239, 1240
manifest, 1240
modular, 435
signing, 1236–1237, 1240–1241, 1242, 1243
Java Beans, 504, 526, 981, 990, 1189–1199
advantages of, 1190
API, 1194–1196
customizers, 1193
definition of the term, 1189
demonstration program, 1196–1199
events, design pattern for, 1192
introspection, 1190–1193, 1196, 1198–1199
persistence, 1193
properties. See Property, Java Bean
serialization, 1193
.java filename extension, 25
Java Community Process (JCP), 18
Java Control Panel, 1237, 1239, 1242
Java EE SDK, 1202, 1206
Java Foundation Classes (JFC), 1012
java (Java application launcher), 26, 27, 191, 314, 436, 1102
and main( ), 27
and modules, 409, 415, 436
Java Native Interface (JNI), 326
Java Network Launch Protocol (JNLP). See JNLP (Java Network Launch Protocol)
files
java package, 191, 197
Java Runtime Environment (JRE), 417
Java SE 7, 16–17
Java SE 8, 17
Java SE 9, 17–18
Java Virtual Machine (JVM), 10, 11, 13, 14, 18, 26, 27, 487, 510, 525
Java Web Start, 11, 18, 1235–1243, 1255
  application signing, 1235, 1236–1237, 1240–1241, 1242, 1243
  example using the local file system, 1239
  and JAR files, 1235, 1236–1237, 1238, 1239, 1240
  and JavaFX, 1101, 1235, 1239
  and JNLP files, 1235, 1236, 1237–1239, 1240, 1241–1242, 1243
  and javaws, 1243
  and Swing, 1235–1236, 1239
  versus applets, 1235–1236
  with an applet, using, 1243
java.applet package, 1255
java.awt package, 769, 772, 802, 880, 1022
  classes, tables of some, 802–804
java.awt.Dimension class, reflection example using the, 990–991
java.awt.event package, 769, 771, 772, 783, 794, 1021, 1022
  adapter classes, table of commonly used, 795
  event classes, table of commonly used, 773
  interfaces, table of commonly used, 783
java.awt.event.InputEvent class. See InputEvent class
java.awt.event.KeyEvent class. See KeyEvent class
java.awt.image package, 879, 885, 890, 901, 904
java.base module, 417, 467, 524, 527, 663, 717, 751, 769, 802, 906, 956, 981, 990, 997, 1002
java.beans package, 1192, 1194–1196
  classes, table of, 1194–1195
  interfaces, table of, 1194
java.desktop module, 417, 769, 880, 1016, 1194, 1255
java.instrument module, 525
  automatically imported by JShell, 1252–1253
classes, list of, 670. See also Streams, byte; Streams, character
    interfaces, list of, 670
java.io.Externalizable interface, 711, 1193
java.io.IOException. See IOException
java.io.Serializable interface, 1193. See also Serializable interface
java.lang package, 197, 230, 286, 295, 308, 314, 320, 356, 359, 417, 439, 467–526, 676
    classes and interfaces, list of, 467
    implicit importation of the, 197, 467
    subpackages, 524–526
java.lang.annotation package, 285, 295, 302, 524, 525
java.lang.annotation.RententionPolicy enumeration, 285, 525
java.lang.image package, 887
java.lang.instrument package, 524, 525
java.lang.invoke package, 524, 525
java.lang.management package, 524, 525
java.lang.module, 519, 524, 525
java.lang.ref package, 525
java.lang.reflect package, 286, 291, 525–526, 981, 990
    classes, table of, 990
java.management module, 525
java.net package, 749, 763
    classes and interfaces, list of, 750–751
java.nio package, 306, 669, 717, 718
java.nio.channels package, 717, 720, 722
java.nio.channels.spi package, 717
java.nio.charset package, 717
java.nio.charset.spi package, 717
java.nio.file package, 673, 717, 722
java.nio.file.attribute package, 717, 722, 726
java.nio.file.spi package, 717, 722
java.nio.file.WatchService, 748
java.prefs module, 666
java.rmi module, 994
java.rmi package, 981, 994
java.text package, 981, 997
java.time package, 618, 981, 1001, 1002, 1007
java.time.format package, 1001, 1003, 1004
java.time.temporal.ChronoUnits, 933
java.util package, 424, 527–528, 592, 609, 769, 772, 961, 976
  automatically imported by JShell, 1252
  classes, list of top-level, 527–528
  interfaces defined by, list of, 528
  subpackages, 663–667
java.util.concurrent package, 663, 906–907, 932, 938
java.util.concurrent.atomic package, 663, 906, 907, 936, 937
java.util.concurrent.locks package, 663, 906, 907, 934, 935, 936
java.util.function package, 17, 407, 523, 556, 574, 590, 609, 663, 962, 963, 968, 975
  functional interfaces defined by, table of, 664–666
java.util.jar package, 663
java.util.List class. See List class (java.util)
java.util.logging package, 663, 666
java.util.prefs package, 663, 666
java.util.regex package, 663, 667, 981
java.util.spi package, 663, 667
java.util.stream package, 17, 663, 667, 956, 972, 980
java.util.zip package, 663, 667
java.xml module, 417
JAVA_HOME environmental variable, 434
javac (Java compiler), 25–26, 191, 298, 362, 1102, 1246, 1248
  and modules, 409, 410, 414–415, 436
  and multi-module compilation mode, 419
javadoc, 18, 1227–1233
  tags, 1227–1232
JavaFX, 17, 305, 786, 787, 801, 829, 1095–1113
  and automatic rendering, 1096, 1109–1113
  controls. See Control(s), JavaFX
  event handling, 1102, 1104–1109
  images, support for, 1115–1117
  and Java Web Start, 1235, 1239
  launcher thread, 1102
  layout panes, 1097, 1100, 1101, 1108–1109, 1168, 1177, 1186
  menus. See Menus, JavaFX
  nodes. See Node(s), JavaFX
packages, 1096
repainting, 1096, 1109, 1111
scene, 1096, 1097, 1100, 1101, 1102, 1177
scene graph, 1097, 1100, 1102–1104, 1108, 1109, 1113, 1116, 1117, 1147, 1154, 1162, 1164, 1165, 1178, 1179, 1186
stage, 1096, 1097, 1100, 1101, 1102
versus Swing, 1095, 1096, 1109

JavaFX application
class, 1097–1098
compiling and running a, 1101–1102
launching a, 1098
life-cycle methods, 1097–1098, 1100
modular, 1098
skeleton, 1098–1101
thread, 1102
javafx.application package, 1096, 1097, 1100
javafx.base module, 1096
javafx.beans.value package, 1129
javafx.collections package, 1103, 1136
javafx.controls module, 1096
javafx.event package, 1105, 1106
javafx.geometry package, 1109
javafx.graphics module, 1096, 1098
javafx.scene package, 1096, 1100
javafx.scene.canvas package, 1109
javafx.scene.control package, 1102, 1105, 1115, 1126, 1132, 1161
javafx.scene.effect package, 1155, 1186
javafx.scene.image package, 1115
javafx.scene.input package, 1171
javafx.scene.layout package, 1096, 1097, 1100
javafx.scene.paint package, 1111
javafx.scene.paint.Color class, 1111, 1156
javafx.scene.shape package, 1113
javafx.scene.text package, 1110, 1160
javafx.scene.transform package, 1156, 1186
javafx.stage package, 1096, 1100
javafx.stage.PopupWindow, 1175
javafxpackager tool, 1098, 1102
javap, 373
javaws tool, 1243
javax.imageio package, 880, 904
javax.servlet package, 1205, 1206–1210, 1212
   interfaces and classes, list of core, 1206–1207
javax.servlet.http package, 1206, 1212–1217
   interfaces and classes, list of some, 1212
javax.swing package, 1014, 1016, 1018, 1019, 1029, 1052
   classes, list of, 1014–1015
javax.swing.event package, 1021, 1032, 1047, 1052
javax.swing.table package, 1055
javax.swing.tree package, 1052
JButton class, 1015, 1023, 1029, 1033–1035, 1060, 1063, 1081
JCheckBox class, 1029, 1033, 1036, 1038–1039, 1081
JCheckBoxMenuItem class, 1060, 1071, 1072–1073, 1081
JComboBox class, 1029, 1049–1051
JComponent class, 1014, 1015, 1024, 1025, 1029, 1033, 1061, 1071, 1260
JDialog class, 1015, 1091
JFormattedTextField class, 1091
JFrame class, 1015, 1016–1017, 1018, 1019–1020, 1028, 1260
   adding a menu bar to a, 1062, 1064, 1067
   content pane layout manager, 1019, 1022–1023
JIT (Just-In-Time) compiler, 10, 14
JLabel class, 1015, 1016, 1017, 1019, 1021, 1024, 1029–1031, 1067
JLayeredPane class, 1015
jlink tool, 18, 434–435
JList class, 1029, 1046–1049
JMenu class, 1060, 1061, 1062–1063, 1064
   mnemonic, 1068
JMenuBar class, 1060, 1061–1062, 1064
JMenuItem class, 1060, 1061, 1062, 1063, 1064, 1071, 1072
   accelerator key, 1069, 1070
   action to create a, using an, 1081
   and action events, 1063, 1064, 1067, 1068
   mnemonic, 1068, 1069–1070
JMOD files, 18, 434, 435
JNLP (Java Network Launch Protocol) files
   and applets, 1243, 1256
   and Java Web Start, 1235, 1236, 1237–1239, 1240, 1241–1242, 1243
   and JavaFX applications, 1101, 1102
jnlp element, 1237, 1238
join( ), 240, 248–250, 456–457, 511, 933, 939, 949, 950, 953
JOptionPane class, 1091
Joy, Bill, 6
JPanel class, 1015, 1016, 1026, 1028, 1042, 1044
JPEG image file format, 879
JPopupMenu class, 1060, 1073–1076, 1081
   and mouse events, 1074, 1075–1076
JRadioButton class, 1029, 1033, 1036, 1039–1041, 1081
JRadioButtonMenuItem class, 1060, 1072–1073, 1081
JRootPane class, 1015
JScrollBar class, 1015
JSeparator class, 1060, 1062
JScrollPane class, 1029, 1044–1046, 1047, 1052, 1053, 1055
jshell, 1245
JShell, 18, 1245–1254
   commands, 1248, 1253–1254
   and state information, 1245, 1247
JSpinner class, 1091
JTabbedPane class, 1029, 1042–1044
JTable class, 1029, 1055–1057
JTextCompenent class, 1031
JTextField class, 1029, 1031–1033
JToggleButton class, 1029, 1033, 1035–1037, 1039
JToggleButton.ToggleButtonModel class, 1036
JToolBar class, 1060, 1077–1079
   adding an action to a, 1081
JTree class, 1029, 1051–1054
Jump statements, 83, 102–110
Just In Time (JIT) compiler, 10, 14
JVM (Java Virtual Machine), 11, 13, 14, 18, 26, 27, 487, 510, 525
JWindow class, 1015
Kernighan, Brian, 4
Key codes, virtual, 778, 792
KeyAdapter class, 795, 796
Keyboard events, handling, 790–794
KeyCombination class, 1171
keyCombination( ), 1171
KeyEvent class, 773, 775, 776, 778, 1068, 1069
keyPressed( ), 784–785, 790, 792
keyReleased( ), 784–785, 790
keys( ), 599, 600, 601
keySet( ), 561, 563, 602, 660, 763
keystore, 1237, 1240, 1241
KeyStroke class, 1069
keytool command-line tool, 1237, 1240, 1241
keyTyped( ), 784–785, 790, 792
Keywords
   context-sensitive, 36, 410
   restricted, 410
   table of Java, 35

L
Label
   AWT standard control, 830, 831–832
   Swing, 1017, 1019, 1029–1031
   used with break statement, 106–108
   used with continue statement, 109
Label class
   AWT, 803, 831
   JavaFX, 1102, 1118
Label, JavaFX, 1102–1104
   adding an image to a, 1118–1120
Labeled class, 1102, 1105
Lambda expression(s), 17, 379–396, 406–407, 556
as arguments, passing, 389–391
block, 380, 385–387
body, 380, 385, 386
and comparators, 576–577, 580
definition of, 379
and exceptions, 382, 392–393
and generics, 387
to handle action events, 836–837, 1023–1024, 1040, 1061, 1105, 1109, 1162, 1169
parameters, 380–381, 382, 383–385, 393
and the stream API, 955
target type, 380, 381, 382, 387, 389, 391, 393
and variable capture, 393–394
Lambda arrow operator (→), 17, 63, 81, 380
last( ), 536, 862
lastElement( ), 594, 595
lastIndexOf( ), 450, 451–452, 464–465, 533, 534, 594, 595
lastKey( ), 565
Late binding, 186
launch( ), 1098, 1100
Layered pane, 1015–1016
Layout managers, AWT, 805, 829, 832, 854–869
default, 855
Layout panes, JavaFX, 1097, 1100, 1101, 1108–1109, 1168, 1177, 1186
LayoutManager interface, 855
Lazy behavior (stream API stream), 958
length instance variable of arrays, 149–151
length( ), 155, 442, 459, 522, 612
Lexer (lexical analyzer), 609
Libraries, class, 25, 36
Library, compact profiles of the API, 334
Lindholm, Tim, 6
LineNumberInputStream deprecated class, 670
LineNumberReader class, 308
lines( ), 705, 725, 959
LinkedBlockingDeque class, 933
LinkedBlockingQueue class, 933
LinkedHashMap class, 568, 571–572
LinkedHashSet class, 541, 547–548
LinkedList class, 541, 545–546
  example program using the, 559–560
  from a stream API stream, obtaining a, 975
LinkedTransferQueue class, 933
List
  controls, 830, 844–847
  event source, as an, 773, 777, 782, 845, 1104
  pop-up, 841
List class (java.awt), 803, 844, 845
List interface (java.util), 530, 533–535, 541, 545, 546, 553, 554, 587, 593, 594, 1103, 1136, 1140, 1141, 1163
  from a stream API stream, obtaining an instance of the, 972–974
  methods, table of, 534
List, Swing, 1046–1049
List view, 1136–1141
  change events, handling, 1137
  multiple selections in a, enabling, 1140–1141
  scroll bars, 1139–1140
list( ), 604, 725
  and directories, 671, 673–675
list( ), ThreadGroup, 513, 515
listFiles( ), 675–676
ListIterator interface, 530, 551, 553–555, 556
  methods, table of, 553
listIterator( ), 534, 553
ListModel interface, 1047
ListResourceBundle class, 660–662
ListSelectionEvent class, 1047, 1048, 1055
ListSelectionListener interface, 1047, 1048
ListSelectionModel interface, 1047, 1055
ListView class, 1136–1141
Literals, 34, 43–46
  class, 288
  regular expression, 983
  string, 46, 442
LocalDate class, 1002, 1003, 1006, 1007
LocalDateTime class, 1002, 1003, 1006, 1007
Locale class, 456, 625–626, 998
Locale Data Markup Language (LDML), 626
Locale.Builder class, 626
Locale.IsoCountryCode, 626
LocalTime class, 1002, 1003, 1006, 1007
Lock interface, 907, 934, 935, 936
methods, table of, 934
lock( ), 907, 934, 935
Locks, 934–936
reentrant, 935, 936
Log, program, 499
log( )
math method, 506
servlet method, 1208, 1210
Logical operators
bitwise, 69–71
Boolean, 77–79
long, 37, 38, 39–40, 43
and automatic type conversion, 50
and automatic type promotion, 52
literal, 44
Long class, 277, 278, 467, 473, 480, 481
methods, table of, 478–480
LongAccumulator class, 937
LongAdder class, 937
LongBuffer class, 719
longs( ), 628
LongStream interface, 958, 959
longValue( ), 278, 468, 470, 472, 474, 475, 476, 479
Look and feels, 1012–1013
lookup( ), 995
Loop(s), 83
Boolean object to control, using a, 283
continue statement and, 108–109
do-while, 92–95
for. See for loop
infinite, 98–99, 105
nested, 103–104, 106, 107–108
with polling, event, 238, 255
while, 81–92
Low surrogate char, 485

M

main (default name of main thread), 242
main(), 27–28, 111, 112, 114, 144, 147
   and applets, 1256
   and the java application launcher, 27
   and a JavaFX application, 1100
   and command-line arguments, 27, 156–157
   and Swing programs, 1020
major(), 492
makeGUI(), 1262
MalformedURLException, 757
Map interface, 561–564, 565, 568, 572, 599, 600, 602
   methods, table of, 562–564
map(), 615, 616, 721, 732, 733, 736
   and stream API streams, 957, 968–972
Map(s), 529, 560–572
   classes, 568–572
   collection-view of a, obtaining a, 529, 560, 561
   flat, 972
   interfaces, 561–567
   and stream API streams, 968–972
   submaps of, 564–565
Map.Entry interface, 561, 565, 569
   methods, table of non-static, 567
MapMode.PRIVATE, 732, 733
MapMode.READ_ONLY, 732, 733
MapMode.READ_WRITE, 732, 733, 736
MappedByteBuffer class, 719, 733
mapToDouble( ), 957, 971
mapToInt( ), 957, 971–972
mapToLong( ), 957, 971
mark( ), 679, 680, 685, 689, 692, 699, 705, 719
markSupported( ), 679, 680, 689, 692, 699, 705
Matcher class, 981, 982–983, 984, 985, 988, 989
matcher( ), 982
matches( ), 457, 982, 986, 989
Math class, 47, 133, 505–509
  exponential functions, methods for, 506
  miscellaneous methods, table of, 508
  rounding methods, table of, 506–507
  and static import example, 329–331
  trigonometric functions, methods, for, 505
max( ), 400–402, 470, 472, 476, 479, 507, 957, 962, 963
  algorithm defined by Collections, 583, 586
MAX_EXPONENT, 469
MAX_PRIORITY, 250–251, 510
MAX_RADIX, 482
MAX_VALUE, 469, 480, 482
MediaTracker class, 803
Member, class, 21, 112
  access and inheritance, 165–166
  access, table of, 193
  controlling access to a, 143–146, 192–196
  static, 147–148
Member interface, 526, 990
Memory
  allocation using new, 54, 55, 115–116
  deallocation, 127
  leaks, 314, 319, 677
  management, in Java, 13, 127
  and the Runtime class, 487–488, 490
MemoryImageSource class, 885–887, 890
Menu bars and AWT menus, 829, 869–874
  action command string of, 870
  and events, 870
Menu, Choice control as a form of, 841
Menu class
  AWT, 803, 869, 870, 874
  JavaFX, 1164, 1163, 1164, 1165, 1169, 1171
Menu item as an event source, AWT, 773, 777, 782, 870
Menu(s), JavaFX, 1161–1186
  accelerator keys, 1161, 1170–1171
  check menu items, 1162, 1173–1175
  classes, table of core, 1162
  context, 1161, 1162–1163, 1175–1178
  demonstration program, 1181–1186
  events, handling, 1162, 1165, 1169–1170
  and images, 1164, 1172–1173
  items, 1161, 1162, 1164–1165
  main, creating a, 1162, 1163–1164, 1165–1170
  menu bar, 1161, 1163–1164, 1165, 1168, 1169
  mnemonics, 1161, 1170, 1171
  popup, 1161, 1162, 1163, 1175
  radio menu items, 1162, 1173–1175
  and separators, 1162, 1164, 1169
  standard, 1161
  and submenus, 1161, 1162, 1164, 1169
  and toolbars, 1161, 1163, 1179–1180
  and tooltips, 1179
Menu(s), Swing, 1059–1091
  accelerator keys, 1059, 1068, 1069–1070, 1083
  action command string, 1060–1061, 1068
  action to manage multiple components of a, using an, 1059, 1079–1084
  and check boxes, 1071, 1072–1073
  classes, interaction of core, 1060–1061
  demonstration program, 1085–1091
  events, 1060–1061, 1063, 1064, 1067–1068, 1071, 1072, 1074, 1075–1076
  and images, 1070–1071
  item as an event source, 772, 777, 782
  main, creating a, 1064–1068
  menu bar, 1059, 1061–1062, 1064, 1067, 1075, 1077
  mnemonics, 1059, 1063, 1068, 1069–1070, 1083–1084
popup, 1059, 1060, 1073–1076
and radio buttons, 1071, 1072–1073
and submenus, 1060, 1062, 1063, 1064
and toolbars, 1059, 1060, 1077–1079
and tooltips, 1071, 1077, 1078, 1079
MenuBar class
  AWT, 803, 869, 870
  JavaFX, 1162, 1163–1164, 1165
MenuDragMouseEvent, 1061
MenuEvent, 1061
MenuItem class
  AWT, 803, 869–870
  JavaFX, 1162, 1163, 1164–1165, 1169, 1170, 1171, 1173, 1176
MenuKeyEvent, 1061
MenuListener, 1061
Metadata, 279, 284. See also Annotation(s)
Metal look and feel, 1013
Method class, 287, 290, 291, 526, 990, 992, 1196
Method reference(s), 379, 394–402
  and the Collections Framework, 400–402
  and generics, 399–402
  to instance methods, 395–399
  to static methods, 394–395
  to a superclass version of a method, 399
Method(s), 21, 112, 117–123
  abstract. See Abstract method(s)
  and annotations, 285, 304
  and autoboxing/unboxing, 280–281
  bridge, 372–373
  calling, 119, 120
  collector, 972
  default interface, 17, 18, 199, 209–213, 379, 381
  dispatch, dynamic, 180–183
  and the dot (.) operator, 113, 119
  factory, 265–266, 751
  final, 149, 186
  general form, 117–118
generic, 336, 348, 354–357, 375
getter, 1190–1191
hidden, using super to access, 172–173, 178
inlining, 186
interface. See Interface methods
and Java Bean introspection, 1192
and JShell, 1248–1249
lookup, dynamic, 201
native, 326
overloading, 131–136, 160–162, 179, 373–374
overriding. See Overriding, method
and parameters, 118, 121–123
passing an object to, 139–140
recursive, 141–143
reference. See Method reference(s)
resolution, dynamic, 198, 201, 202, 206
returning an object from, 140–141
returning a value from, 118, 120–121
scope defined by, 48–50
setter, 1190–1191
subclasser responsibility, 184
synchronized, 240, 251–253, 907, 954
synthetic, 1246
type inference and, 356, 370–371
varargs. See Varargs
variable-arity, 157
MethodDescriptor class, 1192, 1195, 1196
MethodHandle class, 525
methodModifiers( ), 993
MethodType class, 525
Microsoft, 8
MIME (Multipurpose Internet Mail Extensions) type, 1201, 1205
min( ), 470, 472, 476, 479, 507, 958, 961, 962, 963
algorithm defined by Collections, 583, 586
minimumLayoutSize( ), 855
minor( ), 492
MIN_EXPONENT, 469
MIN_NORMAL, 469
MIN_PRIORITY, 250–251, 510
MIN_RADIX, 482
MIN_VALUE, 469, 480, 482
mismatch( ), 591
mkdir( ), 676
mkdirs( ), 676
Model-Delegate component architecture, 1014
Model-View-Controller (MVC) component architecture, 1013–1014, 1096
Modifier class, 990, 992, 993
“is” methods, table of, 992
Module class, 518–519
module keyword, 35, 410
module statement, 410, 416, 433
Module(s), 18, 409–436
and access control, 144, 409, 410, 416, 418–419, 433
automatic, 436
and compact profiles, 334
compiling and running code based on, 414–415
creating code based on, 410–414
declaration, 409–410
definition of the term, 409
description, 410
graph, 432–433
Java API library packages and, 18, 409, 417
layers, 436
and legacy code, 417–418
and multi-module compilation mode, 419, 423
naming conventions, 411
open, 433
and packages, 191
path, 191, 414, 415, 418, 434
platform, 417, 435
and services and service providers, example application demonstrating, 425–432
unnamed, 417
module-info.java file, 410, 414, 415, 416
and javadoc, 1228
ModuleDescriptor class, 519, 525
ModuleFinder interface, 525
ModuleLayer class, 519
ModuleLayer.Controller class, 519
ModuleReader interface, 525
ModuleReference class, 525
Modulus operator (%), 63, 65
Monitor, 240, 251, 254, 255, 261
Mouse events, handling, 787–790
MouseAdapter class, 794, 795, 799, 1074, 1075–1076, 1197
mouseClicked( ), 785, 794, 1074
mouseDragged( ), 785, 794, 884
mouseEntered( ), 785, 1074
MouseEvent class, 773, 775, 776, 779–780, 1074
mouseExited( ), 785, 1074
MouseListener interface, 783, 785, 787–790, 795, 796, 1074, 1075–1076
MouseMotionAdapter class, 794, 795
MouseMotionListener interface, 771, 783, 785, 787–790, 794, 795, 796
mouseMoved( ), 785, 794, 884
mousePressed( ), 785, 797, 1074, 1076, 1197
mouseReleased( ), 785, 1074, 1076
MouseWheelEvent class, 773, 780–781
MouseWheelListener interface, 783, 785, 787, 795, 796
mouseWheelMoved( ), 785
Multicore systems, 16–17, 238, 266, 905, 906, 938, 942, 945, 965
MultipleSelectionModel class, 1137, 1139
Multitasking, 237
preemptive, 239
process-based versus thread-based, 237
Multithreaded programming, 8, 13, 237–266, 509
and context switching. See Context switching effectively using, 266
and multicore versus single-core systems, 238
and spurious wakeup, 256
and StringBuilder class, 465
and synchronization. See Synchronization
and threads. See Thread(s)
versus the concurrency utilities, traditional, 905, 954
and parallel programming, 938
versus single-threaded system, 238
MutableComboBoxModel, 1050
MutableTreeNode interface, 1052
MVC (Model-View-Controller) component architecture, 1013–1014, 1096

N
Namespace collisions
between instance variables and local variables, 127
packages and, 189, 197, 331
and static import, 331
Naming class, 994, 995
NaN, 469, 472
nanoTime( ), 496, 497, 946
@Native built-in annotation, 295
native modifier, 326
Natural ordering, 522, 572
naturalOrder( ), 573
Naughton, Patrick, 6
NavigableMap interface, 561, 565, 570
   methods, table of, 566–567
NavigableSet interface, 530, 537–538, 548, 549
   methods, table of, 537
Negative numbers in Java, representation of, 68–69
NEGATIVE_INFINITY, 469
NegativeArraySizeException, 230, 588
.NET Framework, 8
NetBeans, 1102, 1202, 1203
Networking, 749–767
   basics, 749–750
   classes and interfaces, list of, 750–751
new, 54, 55, 115–116, 123, 125, 127, 141, 184, 226, 227
   constructor reference and, 402, 406
   and enumerations, 268, 271
and type inference, 370–371
NEW, 264
New I/O. See NIO
newByteChannel( ), 721, 724, 729, 731, 732, 733, 734, 736
newCachedThreadPool( ), 927
newCondition( ), 934, 935
newDirectoryStream( ), 724, 742, 744–745
newFileSystem( ), 728
newFixedThreadPool( ), 927–928
newInputStream( ), 725, 738–739
Newline, inserting a, 639
newOutputStream( ), 725, 738, 739–740
newScheduledThreadPool( ), 927, 928
next( ), 552, 553, 556, 650, 862, 976, 977
nextBoolean( ), 626, 627, 650
nextBytes( ), 626, 627
nextDouble( ), 208, 626, 627, 650, 655
nextElement( ), 593, 610, 693
nextFloat( ), 626, 627, 650
nextGaussian( ), 626–628
nextInt( ), 626, 627, 650, 655
nextLong( ), 626, 627, 650
nextToken( ), 610
nextX( ) Scanner methods, 648, 650–651, 652, 655
table of, 650
NIO, 669, 717–748
buffers, 718–720
channels, 718, 720–721
charsets, 722
and directories, 742–748
packages, list of, 717
for path and file system operations, using, 740–748
selectors, 722
and the stream API, 725
for stream-based I/O, using, 728, 738–740
NIO and channel-based I/O
copying a file using, 737–738
reading a file using, 729–733
writing to a file using, 733–737
NIO.2, 16, 717, 728, 740
Node class, 1097, 1101, 1105, 1109, 1116, 1118, 1150, 1155, 1156, 1160, 1162, 1163, 1177
Node(s), JavaFX, 1097, 1100, 1101, 1103, 1108, 1109, 1113
disabling, 1160
effects and transforms to alter the look of, using, 1154–1160. See also Effects;
Transforms
hierarchy, 1097
root, 1097, 1100, 1101, 1103, 1105, 1108, 1177, 1178
scrolling capabilities to, adding, 1147–1149
text, 1160
tree, 1150–1151, 1154

noneMatch( ), 980
NORM_PRIORITY, 251, 510
NoSuchElementException, 536, 538, 540, 564, 593, 615, 651, 657
NoSuchMethodException, 231, 287
NOT operator
    bitwise unary (~), 68, 69, 70–71
    Boolean logical unary (!), 77, 78
NotDirectoryException, 742
notepad, 491, 494–495
notify( ), 187, 188, 255–256, 258–259, 262–264, 499, 905, 935, 954
notifyAll( ), 187, 188, 255–256, 499
NotSerializableException, 715
now( ), 1002–1003
null, 36, 125
    alternative to using, 614
Null statement, 92
NullPointerException, 227, 230, 532, 533, 536, 538, 540, 551, 561, 564, 565, 588, 600, 658, 693
    using Optional to prevent a, 614, 616
nullsFirst( ), 573–574
nullsLast( ), 573–574
Number class, 278, 345, 467, 468
NumberFormatException, 230, 278
Numbers
  formatting, 635–636, 639–645
pseudorandom, 626

O
Oak, 6
  as a data type, problems with using the, 340–342
Object class methods
  and functional interfaces, 380
  table of, 187, 499
Object reference variables
  and abstract classes, 184–185, 186
  and argument passing, 138, 139–140
  assigning, 116–117
  declaring, 115
  and cloning, 500
  and dynamic method dispatch, 180–183
  to superclass reference variable, assigning subclass, 168, 172, 180
OBJECT tag, HTML, 1256
Object-oriented programming (OOP), 5, 6, 19–25, 111
  model in Java, 12
Object(s), 21, 111, 116
  creating/declaring, 113, 115–116
  exact copy (clone) of, 499–500
  initialization with a constructor, 123–126
  to a method, passing, 139–140
  monitor, implicit, 240, 254
  as parameters, 136–138
  returning, 140–141
  serialization of. See Serialization
type at run time, determining, 323–325
Object.notify( ). See notify( )
Object.wait( ). See wait( )
ObjectInput interface, 713
  methods defined by, table of, 713
ObjectInputFilter, 714
ObjectInputFilter.Config, 714
ObjectInputFilter.FilterInfo, 714
ObjectInputFilter.Status, 714
ObjectInputStream class, 307, 713–714
methods defined by, table of, 714
ObjectOutput interface, 711–712
methods defined by, table of, 711
ObjectOutputStream class, 307, 712–713
methods defined by, table of, 712
Objects class, 662
Observable class, 609
observableArrayList( ), 1136, 1139, 1141
ObservableList, 1103, 1104, 1136, 1139, 1140, 1141, 1163
ObservableValue, 1129
Observer interface, 609
Octals, 43
   as character values, 45
   and string literals, 46
off( ), 533, 534, 535–536, 551, 552, 561, 563, 564, 615, 616, 933, 980
offer( ), 538, 550
offerFirst( ), 539, 540, 545
offerLast( ), 539, 540, 545
offsetByCodePoints( ), 457, 464
ofLocalizedDate( ), 1003, 1004
ofLocalizedDateTime( ), 1003
ofLocalizedTime( ), 1003
ofNullable( ), 615, 616
ofPattern( ), 1004–1006
   pattern letters, 1005
onAdvance( ), 923–924, 926
open
   keyword, 35, 410
   modifier, 433
open( ), 721
openConnection( ), 758, 760–761
OpenOption interface, 725
opens
  keyword, 35, 410
  statement, 433
Operator(s)
  arithmetic, 63–68
  assignment. See Assignment operator(s)
  bitwise, 68–76
  Boolean logical, 77–79
  conditional-and, 79
  conditional-or, 79
  diamond (<>), 370–371
  parentheses and, 43, 81
  precedence, table of, 81
  relational, 30, 42, 43, 76–77
  ternary if-then-else (?:), 78, 80
Optional class, 614–616, 961, 962, 963
  methods, table of, 614–615
optional( ), 492
OptionalDouble class, 614, 616
OptionalInt class, 614, 616
OptionalLong class, 614, 616
OR operator
  bitwise (|), 68, 69, 70–71
  bitwise exclusive (^), 68, 69, 70–71
    Boolean logical (|), 77, 78
    Boolean logical exclusive (^), 77, 78
OR operator, short-circuit (||) Boolean logical, 77, 79
or( ), 615, 616
Oracle, 16, 1202
Ordinal value, enumeration constant’s, 273, 274
ordinal( ), 273, 274–275, 521
orElse( ), 615
Orientation, 1179
out output stream, 28, 36, 308, 309, 312, 313, 492, 495. See also System.out
out( ), 633, 635
methods, table of, 681
OutputStreamWriter class, 308
Overloading methods, 131–136, 160–162, 179, 373–374
@override, built-in annotation, 295, 297
Overriding, method, 177–183
  and abstract classes, 183–186
  and bridge methods, 372–373
  and dynamic method dispatch, 180–183
  final to prevent, using, 186
  in a generic class, 369–370
  and run-time polymorphism, 180, 181, 183

P
Package(s), 144, 189–198, 215
  access to classes contained in, 192–196, 197
  built-in standard Java classes and, 196, 197
  the default, 190, 196
  defining, 190
  finding, 190–191
  importing, 196–198
  and JShell, 1252–1253
  and modules, 191
  Swing, 1016
Package class, 291, 517–518
  methods, table of, 517–518
package statement, 190, 196
Paint class, 1111
Paint mode, setting the, 818–819
paint( ), 787, 790, 807, 808, 810, 884, 1024–1025, 1198, 1258, 1259, 1260
  lightweight AWT components and overriding, 878
Paintable area, computing, 1025–1026
paintBorder( ), 1024–1025
paintChildren( ), 1024–1025
paintComponent( ), 1024–1025, 1028, 1260
Painting in Swing, 1024–1028
Panel class, 803, 804, 805, 861, 1257
Panes, Swing container, 1015–1016. See also Content pane
Parallel processing, 17, 379, 556, 558
   of a stream API stream, 955, 958, 959, 965–967, 974, 977, 979
Parallel programming. See Programming, parallel
parallel( ), 956, 965–966
parallelPrefix( ), 590
parallelSetAll( ), 590
parallelSort( ), 589–590
parallelStream( ), 531, 533, 959, 965, 966
Parameter(s), 27, 118, 121–123
   and constructors, 125–126
   final, 149
   and lambda expressions, 380–381, 382, 383–385, 393
names and instance variable names, 127
objects as, 136–138
and overloaded constructors, 134–135
and overloaded methods, 131, 179
and the scope of a method, 48
servlet, reading, 1210–1212
type. See Type parameter(s)
   variable-length (varargs), 159, 535
Parameterized types, 336, 338
parameterModifiers( ), 993
Parent class, 1097, 1101, 1105
parse( ), 492, 1006
parseByte( ), 474, 480
parseDouble( ), 472
parseFloat( ), 470
parseInt( ), 477, 480–481
parseLong( ), 479, 480
parseShort( ), 475, 480
Parsing, definition of, 609
Pascal, 4
PasswordField class, 1146
Passwords, reading, 710
Path interface, 671, 673, 722–723, 729, 740, 741, 742–743, 746
   converting a File object into an instance of the, 673, 722, 740
instance for stream-based I/O, using a, 738–740
methods, table of a sampling of, 723
obtaining an instance of the, 725–726, 729, 731, 732, 733, 734, 736
Paths class, 725–726, 729, 731
Pattern class, 981, 982, 985, 988, 989
Pattern matching, regular expressions, 983–989
PatternSyntaxException, 983
Payne, Jonathan, 6
peek( ), 538, 597, 598
peekFirst( ), 539, 545
peekLast( ), 539, 545
Peers, native, 878, 1011–1012
Period class, 1007
Persistence (Java Beans), 1193
Phaser class, 906, 908, 920–927
compatibility with fork/join, 954
PI (Math constant), 505
PIPE, 494
Pipeline for actions on stream API streams, 17, 379, 958, 970–971
PipedInputStream class, 307
PipedOutputStream class, 307
PipedReader class, 308
PipedWriter class, 308
PixelGrabber class, 887–890
Platform class, 1170
Platform.exit( ), 1170
Pluggable look and feel (PLAF), 1012–1013, 1014
Plug-in and pluggable application architecture, 424, 426
PNG file format, 880
Point class, 779, 780, 803
poll( ), 538, 550
pollFirst( ), 537, 539, 545
Polling, 238, 255
pollLast( ), 537, 539, 545
Polygon class, 803, 812
Polymorphism, 5, 20, 23–25
and dynamic method dispatch, 180–183, 184
and interfaces, 198, 201, 206
and overloaded methods, 131, 133, 134
pop(), 539, 540, 597, 598
Popup trigger, 1074, 1076
PopupControl class, 1163, 1175
PopupMenu class, 803, 874
PopupMenuEvent, 1061
Port, 749, 750, 757
Portable Operating System Interface (POSIX), 727
Portability problem, 6–7, 8, 9–10, 11, 12, 13, 18
    and data types, 38
    and thread context switching, 239
Pos enumeration, 1109
POSITIVE_INFINITY, 469
PosixFileAttributes class, 726, 727, 742
PosixFileAttributeView interface, 728
Possessive behavior (regular expression pattern matching), 987
postVisitDirectory(), 746
pow(), 329–331, 506
pre(), 492
Predicate<T> predefined functional interface, 407, 666, 962
preferredLayoutSize(), 855
previous(), 553, 862
preVisitDirectory(), 746
PrimitiveIterator interface, 529, 976
PrimitiveIterator.OfDouble interface, 529, 976
PrimitiveIterator.OfInt interface, 976
PrimitiveIterator.OfLong interface, 976
print(), 29, 36, 312, 313, 444, 694, 708, 1210
printf()
    function, C/C++, 632, 694
    method, Java, 157, 647, 694–696, 708, 709
println(), 28, 29, 36, 188, 312, 313, 444–445, 635, 694, 708, 1210
    and Boolean output, 43
    and String objects, 61
PrintStream class, 307, 309, 312, 647, 693–696
PrintWriter class, 308, 312–313, 647, 707–708, 1205
PriorityBlockingQueue class, 933
PriorityQueue class, 541, 549–550
private access modifier, 27, 144–146, 192–193
and inheritance, 165–166
Process class, 485–486, 491, 492
methods, table of, 488
Process, definition of, 237, 485
Process-based versus thread-based multitasking, 237
ProcessBuilder class, 485, 492–495
methods, table of, 493–494
ProcessBuilder.Redirect class, 494
ProcessBuilder.Redirect.Type enumeration, 494
ProcessHandle class, 485–486
ProcessHandle.Info, 485
Program log, 499
Programming
multithreaded. See Multithreaded programming
object-oriented. See Object-oriented programming
process-oriented, 19, 20, 24
structured, 4, 5
Programming, parallel, 16–17, 239, 556, 906, 907, 938, 965
and the level of parallelism, 941
and specifying the level of parallelism, 941, 945–948, 954
Project Coin, 16
Properties class, 528, 592, 603–608
methods, table of, 604
Properties, environment, 498
Property, Java Bean, 1190, 1198
boolean, 1191
bound and constrained, 1193, 1196
design patterns for, 1190–1191, 1193
PropertyChangeEvent, 1193
PropertyChangeListener interface, 1193, 1194
PropertyDescriptor class, 1192, 1195, 1196, 1198
PropertyPermission class, 662
PropertyResourceBundle class, 660
PropertyVetoException, 1193
protected access modifier, 144, 192–193
Protocols, overview of networking, 749–750
provides
  keyword, 35, 410
  statement, 425, 532
Pseudorandom numbers, 626
public access modifier, 27, 144–146, 192–193
Push buttons, AWT, 830, 833–837
  action command string of, 833, 835, 836, 1033–1044
Push buttons, JavaFX, 1105–1109
  adding an image to, 1120–1123
Push buttons, Swing, 1021–1024, 1033–1035
  action command string of, 1033–1034
push( ), 540, 597, 598
Pushback, 690–692
PushbackInputStream, 307, 688, 690–692
PushbackReader class, 308, 706–707
put( ), 561, 563, 568, 570, 572, 599, 600, 601
  and buffers, 719, 720, 735
putAll( ), 563, 572
PutField inner class, 712–713
putValue( ), 1080–1081, 1082

Q
Query string, 1218
Queue, double-ended, 539–540
Queue interface, 530, 538, 539, 545, 549, 550
  methods, table of, 538
quietlyInvoke( ), 953
quietlyJoin( ), 953

R
Race condition, 253
Radio buttons, 839
  JavaFX, 1125–1128, 1129–1132
  Swing, 1039–1041
and Swing menus, 1072–1073
RadioButton class, 1125, 1126, 1132
RadioMenuItem class, 1162, 1173
Radix, 473
radix( ), 657
Random class, 208, 626–628
methods, table of core, 627
RandomAccess interface, 530, 560
RandomAccessFile class, 698, 721
range( ), 551, 552
Raw types, 360–362
READ, 494
read( ), 95, 307, 308, 309–310, 314–315, 524, 680, 689, 691, 699, 707, 713, 714,
    721, 730, 731, 738, 880–881
Readable interface, 524, 647, 653, 699
ReadableByteChannel interface, 647
readAttributes( ), 725, 727, 741–742
readBoolean( ), 697, 714
readDouble( ), 697, 714
Reader class, 307–308, 309, 678, 679, 699, 700, 702, 711
    methods defined by, table of, 699
readExternal( ), 711
readInt( ), 697, 714
readLine( ), 310–312, 480, 709, 1210, 1257
readObject( ), 713, 714, 715
readPassword( ), 709, 710
ReadWriteLock interface, 936
Real numbers, 40
rebind( ), 994–995
receive( ), 765
Recursion, 141–143
    and the Fork/Join Framework divide-and-conquer strategy, 942
RecursiveAction class, 907, 938, 940, 942, 943, 944, 948
RecursiveTask class, 907, 938, 940, 942
    example program using, 948–951
Redirect class, 494
reduce( ), 958, 963–965, 966–967, 968–969
Reduction operations, 963–965
   mutable, 975
ReentrantLock, 935
ReentrantReadWriteLock, 936
Reflection, 286, 433, 525–526, 981, 990–993
   and annotations, 286–291
Region class, 1097, 1105
regionMatches( ), 447–448
register( ), 920
Regular expressions, 458, 609, 647, 655, 667, 981–989
   definition of the term, 981
   syntax, 983
      wildcards and quantifiers, 981, 983, 985–987
reinitialize( ), 952
Relational operators, 30, 42, 43, 76–77
Relative index, 645–646
release( ), 908–911
Reluctant behavior (regular expression pattern matching), 986–987
Remote interface, 994
Remote method invocation (RMI), 14, 710, 981, 994–997
RemoteException, 994
remove( ), 531, 532, 534, 538, 546, 551, 552, 553, 563, 599, 600, 601, 830, 1020,
   1061, 1063, 1104, 1156, 1163, 1164
removeActionListener( ), 1023
removeAll( ), 531, 532, 830
removeAttribute( ), 1215, 1222
removeEldestEntry( ), 572
removeElement( ), 594, 595
removeElementAt( ), 594, 595
removeFirst( ), 540, 545
removeIf( ), 531, 532
removeKeyListener( ), 771
removeLast( ), 540, 545
removeTListener( ), 1192
removeTypeListener( ), 771
renameTo( ), 672
repaint( ), 787, 790, 795, 796, 797, 808–809, 1025, 1109, 1198, 1259
@Repeatable annotation, 295, 302, 303
REPL (read-evaluate-print loop) execution, 1245
replace( ), 435, 463, 563
replaceAll( ), 457, 533, 534, 563, 983, 988
replaceRange( ), 853
ReplicateScaleFilter class, 890
requires keyword, 35, 410
requires statement, 410, 416, 417
   using static with a, 433, 434
   using transitive with a, 420–424
reset( ), 657, 679, 680, 685, 687, 689–690, 692, 699, 705, 719
resolve( ), 722, 723
Resource bundles, 657–662
ResourceBundle class, 657–660
   methods, table of, 658–660
   and modules, 660
ResourceBundle.Control class, 658
resume( ), 14, 262, 510, 512
retainAll( ), 531, 532
@Retention built-in annotation, 286, 295
RetentionPolicy enumeration, 286, 525
return statement, 109–110, 118
   in a lambda expression, 386
reverse( )
   algorithm defined by Collections, 583
      StringBuffer method, 462
reversed( ), 573, 576
reverseOrder( )
   collection algorithm, 583, 585–586
      Comparator method, 573
rewind( ), 719, 731, 734, 735
RGB (red-green-blue) color model, 815
   default, 885
RGBImageFilter class, 890, 892–893
   example program demonstrating the, 893–904
RGBtoHSB( ), 816
Richards, Martin, 4
Ritchie, Dennis, 4, 5
rmi protocol, 995
RMI (Remote Method Invocation), 14, 710, 981, 994–997, 1202
rmic compiler, 996
rmiregistry (RMI registry), 996, 997
Rotate class, 1156–1157
  program demonstrating, 1157–1160
Run-time
  system, Java, 10. See also Java Virtual Machine (JVM)
  type information, 14, 323, 366–368, 504
run( ), 240, 243, 244, 380, 509, 511, 629, 952, 1020
    overriding, 245, 246, 629
    using a flag variable with, 262–264
RUNNABLE, 264
Runnable interface, 240, 242, 380, 509, 628, 629, 905, 951, 952, 1020
  implementing the, 243–244, 246
Runtime class, 485, 486–492, 948
  executing other programs and, 491–492
  memory management and, 487–488, 490
  methods, table of some, 489
RUNTIME retention policy, 285–286, 287, 290
Runtime.exec( ), 485, 489, 491–492
Runtime.Version class, 492
Runtime.version( ), 489, 492
RuntimeException class, 218, 219, 227, 230, 234
RuntimePermission class, 519

S
@SafeVarargs built-in annotation, 295, 297
SAM (Single Abstract Method) type, 380
Sanbox, 10, 1236
save( ), 603
Scale class, 1156, 1157
  program demonstrating, 1157–1160
Scanner, 609
Scanner class, 647–657
closing an instance of the, 653
constructors, 647, 648
delimiters, 647, 655–656
demonstration programs, 651–655
hasNextX( ) methods, table of, 649
how to use, 647–648, 650–651
methods, miscellaneous, 656–657
nextX( ) methods, table of, 650
Scene class, 1096, 1097, 1100, 1101
schedule( ), 629, 630
ScheduledExecutorService interface, 927
ScheduledThreadPoolExecutor class, 907, 927
Scientific notation, 44, 635–636
Scopes in Java, 47–50
    nested, 48–49, 152
Scroll bars, 830, 847–850, 1044, 1045, 1139–1140, 1147–1149, 1150
    as an event source, 774, 782, 848
Scroll pane, 1044–1046, 1147–1149
Scrollbar class, 803, 847
ScrollPane class, 803, 1147–1149
search( ), 597, 598
Security manager, 314, 495, 519, 677, 694, 997, 1202
Security problem, 8, 9, 10, 12, 18
    and servlets, 1202
security( ), 492
SecurityException, 230, 314, 487, 495, 677, 694, 742, 746
SecurityManager class, 519
seek( ), 698
SeekableByteChannel interface, 721, 729, 732, 734
select( ), 842, 845, 850–851, 853
selectedItemProperty( ), 1137, 1139, 1150
selectedToggleProperty( ), 1129
Selection statements, 83–91
SelectionMode, 1140
SelectionModel class, 1137
Selectors, 722
Semaphore, 905, 906, 908–913, 954
and setting initial synchronization state, 913
Semaphore class, 906, 908
send( ), 765
Separable Model architecture, 1014
Separator class, 1132
SeparatorMenuItem class, 1162, 1164
Separators, 35
SequenceInputStream class, 307, 692–693
sequential( ), 956, 967
Serializable interface, 711, 715, 953, 1193
Serialization, 710–716
  example program, 715–716
  and Java Beans, 1193
  and static variables, 711
  and transient variables, 711, 715
serialVersionUID constant, 716
Server process, 749, 763
ServerSocket class, 721, 753, 763–764
service( ), 1202, 1205, 1207, 1211, 1217
ServiceLoader class, 424, 622
Services and service providers, 424–432
  definition of the terms, 424
  module-based example application demonstrating, 425–432
  and modules, 425
Servlet interface, 1206, 1207, 1210
  methods, table of, 1207
Servlet(s), 11, 1201–1223
  advantages of, 1202
  API, 1206
  development options, 1202–1204
  example program for a simple, 1204–1206
  life cycle of, 1202
  parameters, reading, 1210–1212
  and portability, 11
  and security, 1202
  and session tracking, 1222–1223
  using Tomcat to develop, 1202, 1203–1206
ServletConfig interface, 1206, 1208, 1210
ServletContext interface, 1206, 1208

methods, table of various, 1208
ServletException class, 1207, 1210
ServletContext class, 1207, 1210
ServletContext class, 1207, 1210

ServletRequest interface, 1205, 1206, 1208, 1210

methods, table of various, 1209
ServletRequest interface, 1205, 1206, 1208

methods, table of various, 1209
ServletResponse interface, 1205, 1206, 1208

methods, table of various, 1209
Session tracking, HTTP, 1222, 1223
Set interface, 530, 535–536, 546, 551, 561, 565

from a stream API stream, obtaining an instance of the, 972–974
Set-view, obtaining, 569, 602
set( ), 533, 534, 546, 553, 612, 619, 937
setAccelerator( ), 1069, 1171
setActionCommand( ), 836, 870, 1033–1034, 1040
setAlignment( ), 831, 1108–1109
setAll( ), 590
setAllowIndeterminate( ), 1135
setAngle( ), 1156–1157
setAttribute( ), 1208, 1215, 1222
setBackground( ), 807, 815
setBlockIncrement( ), 848
setBorder( ), 1028
setBounds( ), 805, 855
setCharAt( ), 460
setColor( ), 816
setConstraints( ), 864
setContent( ), 1147
setContentDisplay( ), 1119–1120, 1122–1123, 1180
setContentType( ), 1205, 1209
setContextMenu( ), 1176
setDefault( ), 624, 625
setDefaultCloseOperation( ), 1018–1019
setDisable( ), 1160, 1165
setDisabledIcon( ), 1033, 1071
setPrefViewportHeight(), 1147
setPrefViewportWidth(), 1147
setPrefWidth(), 1132, 1137
setPressedIcon(), 1033
setPriority(), 250–251, 512
setPromptText(), 1144
setReadOnly(), 673
setRolloverIcon(), 1033
setRotate(), 1156
setScaleX(), 1156
setScaleY(), 1156
setScene(), 1101
setSelected(), 1126, 1129, 1173
setSelectedCheckbox(), 840
setSelectedIcon(), 1033
setSelectionMode(), 1047, 1140
setSize(), 595, 805, 806, 810, 1018
setState(), 837, 870
setStroke(), 1110–1111
setText(), 831, 850, 853, 1030, 1033, 1108, 1144, 1164
setTitle(), 806, 1100
setToggleGroup(), 1126
setTooltip(), 1160, 1179
setToolTipText(), 1071
setTranslateX(), 1156
setTranslateY(), 1156
setUnitIncrement(), 848
setValue(), 567, 847–848, 1142, 1216
setValues(), 847
setVvalue(), 1147–1148
setVisible(), 806, 809, 810, 1020
setX(), 1157
setXORMode(), 818–819
setY, 1157
Shear class, 1156
Sheridan, Mike, 6
Shift operators, bitwise, 68, 71–75
Short class, 277, 278, 467, 473, 480, 481
   methods defined by, table of, 475
short data type, 37, 38, 39, 43
   and automatic type conversion, 50
   and automatic type promotion, 52, 71
ShortBuffer class, 719
shortValue( ), 278, 468, 470, 472, 474, 475, 477, 479
show( ), 862, 1074, 1075, 1076, 1101, 1178
shuffle( ) algorithm defined by Collections, 583, 584, 586
shutdown( ), 927, 929, 942, 953–954
shutdownNow( ), 953–954
Sign extension, 71, 73–74, 74–75
signal( ), 935
SimpleBeanInfo class, 1193, 1198, 1199
SimpleDateFormat class, 626, 999–1001, 1005
   formatting string symbols, table of, 1000
SimpleFileVisitor class, 747, 748
SimpleTimeZone class, 624–625
sin( ), 40, 505
SingleSelectionModel, 1042
SIZE, 469, 480
size( ), 531, 532, 546, 564, 595, 599, 600, 601, 612, 725, 727, 733, 1163, 1164
skip( ), 657, 680–682, 689, 699, 713
SKIP_SIBLINGS, 746
SKIP_SUBTREE, 746, 747
sleep( ), 240, 241–242, 247, 512, 933
slice( ), 720
Slider box, 847
Snippet, code, 1245, 1247, 1248, 1250, 1253
Socket class, 721, 753–756, 763, 764
Socket(s)
   datagram, 764–765, 767
   overview, 749–750
   and servlets, 1202
   TCP/IP client, 753–756
   TCP/IP server, 753, 763–764
SocketAddress class, 765
SocketChannel class, 721
SocketException, 765
sort( ), 533, 534, 589
  algorithm defined by Collections, 584
sorted( ), 958, 962
SortedMap interface, 561, 564–565
  methods, table of, 565
SortedSet interface, 530, 536, 537
  methods, table of, 536
Source code file, naming a, 25
SOURCE retention policy, 285–286
split( ), 457, 458, 988–989
Spliterator, 523, 529, 533, 556–558
  and arrays, 590
  characteristics, 558
Spliterator interface, 523, 529, 530, 551, 556–558
  methods declared by, table of, 557
  and streamAPI streams, 976, 977–979
splitter( ), 523, 531, 533, 590, 956
Spliterator.OfDouble interface, 558
Spliterator.OfInt interface, 558
Spliterator.OfLong interface, 558
Spliterator.OfPrimitive interface, 558
sqrt( ), 40, 47, 329–331, 506
Stack
  definition of, 23, 128
  frame, 520
  trace, 219–220, 226, 520
  walking, 521
  ways to implement a, 203
Stack class, 528, 541, 592, 597–599
  methods, table of, 598
StackTraceElement class, 232, 520
  methods, table of, 520
StackWalker class, 521
StackWalker.StackFrame interface, 521
Stage class, 1096, 1097, 1100, 1101
StampedLock interface, 936
StandardCopyOption values, partial list of, 737
StandardOpenOption class, 725, 738, 739
   enumeration, table of values for the, 726
StandardOpenOption.CREATE, 726, 734, 739
StandardOpenOption.READ, 726, 736, 738
StandardOpenOption.TRUNCATE_EXISTING, 726, 739
StandardOpenOption.WRITE, 726, 734, 739
Standard Template Library (STL), 529
start( ), 240, 243, 244, 245, 485, 494–495, 512, 982–983, 985
   and applets, 1235, 1257, 1259, 1260, 1262
   and JavaFX, 1097, 1098, 1100, 1101, 1102
startsWith( ), 448, 723
State enumeration, 264
Statements, 28
   null, 92
Statements, control, 29, 42
   iteration, 83, 91–102
   jump, 83, 102–110
   selection, 83–91
static, 27, 147–148, 151, 329
   member restrictions, 375
   used in a requires statement, 434
Static import, 15, 329–331
stop( ), 14, 262, 510, 512
   and applets, 1235, 1257, 1259, 1260
   and JavaFX, 1097, 1098, 1100, 1101, 1102, 1170
store( ), 603, 604, 606–608
str( ), 285
Stream API, 17, 955–980
   and collections, 608, 955, 956, 959, 961, 974
   interfaces, 956–959
   and lambda expressions, 955
   and NIO, 725
Stream interface, 533, 590, 705, 725, 957–958, 979, 980
   methods, table of some, 957–958
   and primitive types, 958, 959
Stream, intermediate operations on a stream API, 958
to create a pipeline of actions, 958, 970–971
lazy behavior of, 958
stateless versus stateful, 958
Stream, stream API
and accumulator operations, 963, 964, 966–967, 975
collection from a, obtaining a, 972–975
and combiner operations, 966–967, 969, 975
definition of the term, 955–956
iterators and a, 976–979
mapping a, 968–972
obtaining a, 959
operations on a, terminal versus intermediate, 958
ordered versus unordered, 967
parallel processing of a, 955, 958, 959, 965–967, 974, 977, 979
parallel, using a, 965–967, 979
reduction operations, 963–965
stream( ), 532, 533, 590, 612, 615, 959, 961, 966, 971
Stream(s), byte, 306–307, 309, 313, 679–698
  buffered, 688–692
classes in java.io, table of, 307
  filtered, 688
  classes in java.io, table of, 308
Stream(s), I/O
  benefits, 716
  buffered, 688–692, 704–707
classes, top-level, 678–679
closing, 677–678
concatenating input to, 692–693
definition of the term, 306, 699
filtered, 688, 716
flushing, 676
and NIO, 728, 738–740
predefined, 308–309
reactive, 907
variables, predefined, 308–309
versus stream API streams, 956
strictfp, 325
StrictMath class, 509
String class, 27, 60–61, 154–156, 439, 458, 522, 647, 982
constructors, 440–442
methods, table of some, 457–458
String(s)
arrays of, 61, 156
changing case of characters in, 455–456, 482–484
comparison, 155, 446–450
constants, 61, 154
converting data into a, 444–445, 454–455
creating, 154, 440–442
extracting characters from, 445–446
formatted, creating a, 633–635
formatting a, 635, 641
immutability of, 154, 439, 452, 458
joining, 456–457
length of a, obtaining the, 155, 442
literals, 46, 442
modifiable, creating and working with, 458–465
modifying, 452–454
numbers to and from, converting, 480–482
as objects, 46, 61, 154, 439
parsing a formatted input, 609–611
reading, 310–312
searching, 450–452
StringBuffer class, 154, 439, 441, 452, 458–465, 522
methods, table of some, 464
StringBufferInputStream deprecated class, 670
StringBuilder class, 154, 439, 441, 452, 465, 522, 632, 633
and synchronization, 465
StringJoiner class, 662
StringReader class, 308
StringTokenizer class, 609–611
methods, table of, 610
stringWidth( ), 826, 827
StringWriter class, 308
strokeLine( ), 1110
strokeOval( ), 1110
strokeRect( ), 1110
strokeText( ), 1110
Stroustrup, Bjarne, 6
Stubs (RMI), 996
Subclass, 22, 163–166, 181
generic, 362–366
subList( ), 533, 534
subMap( ), 564, 565, 567
submit( ), 930
subSequence( ), 458, 464, 522
subSet( ), 536, 537, 549
substring( ), 452–453, 463
Sun Microsystems, 6, 14, 15, 16
super, 147, 169
and bounded wildcard arguments, 354
and interface default methods, 213
and method references, 399
and methods or instance variables, 172–173, 178
super( ), 333
and superclass constructors, 169–172, 176, 246
Superclass, 22, 163–166, 181, 189
abstract, 183–186
generic, 362–364
Supplemental character, definition of, 484
Supplier<T> predefined functional interface, 407, 666, 975
@SuppressWarnings built-in annotation, 295, 297
suspend( ), 14, 262, 510, 512
Swing, 14, 17, 305, 786–787, 829, 1011–1057, 1095
applet, 1016
application, example of a simple, 1016–1021
and the AWT, 801, 829, 1011–1012
component classes, list of, 1014–1015
components. See Components, Swing
containers. See Container(s), Swing
event handling, 1020–1024
history of, 1011–1012
and Java Web Start, 1235–1236, 1239
and JavaFX, 1095, 1096, 1109
menus. See Menu(s), Swing
and MVC architecture, 1013–1014
packages, list of, 1016
and painting, 1024–1028
threading issues, 1020, 1024
*Swing: A Beginner’s Guide* (Schildt), 1011
SwingConstants interface, 1030
SwingUtilities class, 1020
switch statement, 86–91, 106
and auto-unboxing, 282
nested, 90
using enumeration constants to control a, 87, 268–270
using a String to control a, 16, 87, 89–90
versus the if statement, 90–91
Synchronization, 13, 239–240, 251–255
and atomic operations, 936–937
and collections, 540, 585, 592
and deadlock, 260–261
and interprocess communication, 255–260
objects, using, 908–927
race condition and, 253
and StringBuilder class, 465
via synchronized block, 253–255, 585
via synchronized method, 240, 251–252
versus concurrency utilities, traditional, 905, 954
synchronized modifier, 251, 905, 934, 954
used with a method, 251–253
used with an object, 253–255
synchronizedList( ), 584, 585
synchronizedSet( ), 584, 585
Synchronizers, 905, 906–907
SynchronousQueue class, 933
System class, 28, 36, 308, 495–498
    methods, table of, 495–496
System.console( ), 495, 709
System.err standard error stream, 308, 309, 495
System.exit( ), 495, 787, 790, 807, 809, 1068, 1170
System.getProperties( ), 496, 603
System.getProperty( ), 496, 498
System.in standard input stream, 308, 309, 492, 495, 647, 708
System.in.read( ), 95
System.Logger interface, 499
System.LoggerFinder class, 499
System.nanoTime( ), 496, 497, 946
System.out standard output stream, 28, 36, 308, 309, 312, 313, 492, 495, 647, 693, 695, 708
    and static import, 331

T
Tabbed panes, 1042–1044
Table, Swing, 1055–1057
TableColumnModel, 1055
TableModel, 1055
TableModelEvent class, 1055
tailMap( ), 564, 565, 567
tailSet( ), 536, 537
@Target built-in annotation, 295, 296, 298
TCP/IP, 14, 750
    client sockets, 753–756
    disadvantages of, 764
    server sockets, 753, 763–764
    See also Transmission Control Protocol (TCP)
TemporalAccessor, 637
TERMINATE, 746, 747
TERMINATED, 264
Ternary if-then-else operator (?:), 78, 80
test( ), 407, 664, 665, 666, 962–963
Text
area, 781, 785, 853–854
components as an event source, 781, 782
editing controls, 830, 850–854
formatting using java.text classes, 981, 997–1002
output using font metrics, managing, 825–828
Text class, 1160
Text fields, 781
   AWT, 850–852
   JavaFX, 1144–1146, 1176–1177
   Swing, 1031–1033
TextArea class
   AWT, 804, 853–854
   JavaFX, 1146
TextComponent class, 804, 850, 853
TextEvent class, 773, 781, 853
TextField class
   AWT, 804, 850–851
   JavaFX, 1144–1146
TexInputControl, 1144
TextInputDialog, 1146
TextListener interface, 783, 785
textValueChanged( ), 785
thenComparing( ), 574, 579–580
thenComparingDouble( ), 574
thenComparingInt( ), 574
thenComparingLong( ), 574
this, 126–127, 147
   and lambda expressions, 393
   and type annotations, 297, 298, 301
this( ), 331–333
Thompson, Ken, 4
Thread class, 14, 240, 241, 246, 262, 264, 509, 510–512, 628, 905, 938
   constructors, 243, 246, 510
   extending, 245–246
   methods, table of, 510–512
ThreadPool, 905, 927–239, 939, 940–942, 945, 948, 953–954
   common, 939, 940, 941, 942, 945, 948, 954
Thread(s)

- communication among, 255–260
- creating, 242–247
- creating and starting a, 265–266
- daemon, 629, 942, 951
- and deadlock, 260–261, 512, 1020
- definition of the term, 237
- executors to manage, using, 907, 927–929
- group, 242, 512–516
- JavaFX, 1102
- local variables, 517
- main, 240–242, 244, 246, 247, 248, 1020
- messaging, 240
- priorities, 239, 250–251, 510
- race condition of, 253
- resuming, 262–264, 512, 514–516
- return a value, that, 929–932
- and spurious wakeup, 256
- states of, possible, 239, 264–265
- stopping, 262
- and Swing, event dispatching, 1020, 1024, 1260
- synchronization. See Synchronization

Thread.UncaughtExceptionHandler interface, 524
ThreadGroup class, 509, 512–516, 524
- methods, table of, 513–514
ThreadLocal class, 517
ThreadPoolExecutor class, 907, 927
- throw, 217, 226–227, 236
Throwable class, 218, 219, 222, 226, 227, 231, 234, 322, 377, 519, 520
- methods defined by, table of, 232
- obtaining an object of the, 226–227
- throws, 217, 227–228, 230
Thumb, 847

time Calendar class instance variable, 618
Time and date
- formatting, 637–638, 981, 997–1001, 1003–1006
java.util classes that deal with, 616–626
strings, parsing, 1006–1007
Time and Date API, 618, 981, 997, 1001–1007
   packages, list of, 1001
timedJoin(), 933
timedWait(), 933
TIMED_WAITING, 264
Timer class, 628–630
   methods, table of, 630
TimerTask class, 628–630
   methods, table of, 629
TimeZone class, 623–624
   methods defined by, table of some, 623–624
to
   keyword, 35, 410
   clause, 419, 433
to( ), 494
toAbsolutePath(), 723, 740
toArray(), 532, 543–544, 958
toBinaryString(), 477, 479, 480, 481–482
toCharArray(), 446
toChronoUnit(), 933
toDays(), 933
toDegrees(), 508, 509
ToDoubleFunction functional interface, 666, 971
toFile(), 722
ToggleButton class, 1123–1125
   adding an image to a, 1123
ToggleButton class, Swing, 1035–1037
Toggle interface, 1123, 1125, 1132
Toggle group, 1125, 1126, 1128
   handling change events in a, 1128–1129
   and RadioMenuItems, 1173
ToggleButton class, 1123–1125, 1126
ToggleGroup class, 1126, 1128, 1132
toHexString( ), 471, 472, 477, 480, 481–482
toHours( ), 933
Tokens, 609, 647, 655
tokens( ), 657
toLanguageTag( ), 626
toList( ), 972, 974
toLocalDate( ), 1003
toLocalTime( ), 1003
toLowerCase( ), 455–456, 483, 485
Tomcat, 1202, 1203–1206
toMicros( ), 933
toMillis( ), 933
toMinutes( ), 933
toNanos( ), 933
toOctalString( ), 477, 480, 481–482
Toolbar class, 1163, 1179
Toolbars, 1059, 1060, 1077–1079, 1161, 1163, 1179–1180
undocked, 1077
Tooltip class, 1115, 1160
Tooltips, 1071, 1077, 1078, 1079, 1115, 1160, 1179–1180
TooManyListenersException, 1192
toPath( ), 673, 722, 740
toRadians( ), 508, 509
toSeconds( ), 933
toSet( ), 972, 974
toString( ), 187, 188, 222, 231, 232, 278, 285, 291, 313, 444, 455, 471, 472, 474,
475, 477, 480, 481, 487, 499, 503, 512, 514, 518, 519, 520, 521, 522, 543,
590, 595, 601, 612, 613, 615, 617, 631, 633, 635, 694, 708, 722, 723, 753,
772, 820, 826, 953, 990, 1052
advantages to overriding, 188, 444–445
totalCPUDuration( ), 485
totalMemory( ), 488, 489, 490
toUpperCase( ), 455–456, 483
toZonedDateTime( ), 622
Transform class, 1156
Transforms, 1156–1157
program demonstrating, 1157–1160
transient modifier, 322–323, 1193
transitive keyword, 35, 410, 420–424
Translate class, 1156
translatePoint( ), 779
Transmission Control Protocol (TCP)
  definition of, 749
  and stream-based I/O, 750
  See also TCP/IP
TreeExpansionEvent class, 1052
TreeExpansionListener interface, 1052
TreeItem class, 1150, 1151, 1154
TreeMap class, 568, 570–571, 572, 608
  example using a comparator, 577–580
TreeModel, 1052
TreeModelEvent class, 1052
TreeModelListener interface, 1052
TreeNode interface, 1052
TreePath class, 1052
Trees
  JavaFX, 1150–1154
  Swing, 1051–1054
TreeSelectionEvent class, 1052
TreeSelectionListener interface, 1052, 1053
TreeSelectionModel, 1052
TreeSet class, 541, 547, 548–549, 572, 608
  example using a comparator for sorting an instance of the, 575–577
TreeView class, 1150–1154
trim( ), 454
trimToSize( ), 464, 543, 595
ture, 36, 42, 43, 45, 77, 78, 79
TRUE, 485
True and false in Java, 45, 77
Truncation, 51–52
try block(s), 217, 218, 220–226, 227–229, 236
  nested, 224–226
advantages to using, 319, 321, 678
tryAdvance( ), 556–558, 977
tryLock( ), 907, 934–935
trySplit( ), 978–979
tryUnfork( ), 953
Two’s complement, 68–69
TYPE, 469, 480, 482, 485
Type argument(s), 338, 340, 344
   and bounded types, 345–347
   and generic class hierarchies, 362
   and generic interface implementation, 360
   and type inference, 356, 370–371
Type conversion
   automatic, 37, 50, 132–133
   narrowing, 50
   widening, 50
Type enumeration, 494
Type interface, 526
Type parameter(s)
   and bounded types, 344–347, 359–360
   cannot create an instance of a, 375
   and class hierarchies, 363–366
   and erasure, 339, 371
   and primitive types, 340
   and static members, 375
   and type safety, 340
   used with a class, 338, 343–345 347
   used with a method, 338, 354–357
   and wildcard arguments, 347–356
Type safety
   and collections, 585
   and generic methods, 357
   and generics, 335, 336, 339, 340–342
   and raw types, 360–362
   and wildcard arguments, 347–350, 351
type( ), 494
Type(s), 29
annotations, 17, 297–302
bounded, 345–347
casting, 50–52
casting, 50–52
class as a data, 111, 113, 115, 116, 117, 128
class as a data, 111, 113, 115, 116, 117, 128
inference, 356, 370–371, 381, 384, 387, 393
inference, 356, 370–371, 381, 384, 387, 393
non-reifiable, 297
parameterized, 336, 338
promotion, 39, 52–53, 71–73
raw, 360–362
SAM (Single Abstract Method), 380
simple, 37
Types, primitive (simple), 37–38, 116, 138, 276, 340, 468
autoboxing/unboxing and, 279–282, 284, 544
and collections, 544
iterators for, 529
to a string representation, converting, 443, 444, 454–455
to or from a sequence of bytes, converting, 696–698
wrappers for, 276–279, 284, 340, 468–485
Typesafe view of a collection, obtaining a dynamically, 585

U

UDP protocol, 750, 764
UI delegate, 1014
ulp( ), 506, 507
UnaryOperator<T> functional interface, 407, 666
UnavailableException, 1207, 1210
Unboxing, 279
UncaughtExceptionHandler interface, 524
method uncaughtException( ), 524
Unchecked warnings and raw types, 362
UnicastRemoteObject, 994
Unicode, 41, 42, 45, 306, 307, 441, 442, 446, 484, 699
code points, table of some Character methods providing support for, 486
support for 32-bit, 484–485
Unicode Technical Standard (UTS) 35, 626
Uniform Resource Identifier (URI), 763
Uniform Resource Locator (URL). See URL (Uniform Resource Locator)
UNIX, 5, 749
UnknownHostException, 752
unlock( ), 907, 934, 935
unmodifiable… collections methods, 584–585
unordered( ), 956, 967
Unreachable code, 110, 223
unread( ), 691, 706–707
UnsupportedOperationException, 212, 230, 530, 532, 533, 551, 561, 585, 727
update( ), 808, 809, 810
URI (Uniform Resource Identifier), 763
URI class, 763
URL (Uniform Resource Locator), 757, 763, 1201, 1202
query string, 1218
specification format, 757
URL class, 757–758, 760, 761
URLConnection class, 758–761, 763
methods, list of some, 759
useDelimiter( ), 655–656
User Datagram Protocol (UDP), 750, 764
useRadix( ), 657
uses
keyword, 35, 410
statement, 425, 431, 432
UTS 35, 626
UUID class, 662

V

val( ), 285
value (annotation member name), 294, 295
valueChanged( ), 1047, 1048, 1052, 1053
valueOf( ), 270–271, 277, 278, 444, 454–455, 469, 471, 472, 473, 474, 475, 478, 480, 482, 485, 487, 521, 612
values( ), 270–271, 561, 564
van Hoff, Arthur, 6
Varargs, 15, 157–162
   and ambiguity, 161–162
   methods, overloading, 160–161
   and Java’s printf( ), 157
   parameter, 159, 535
Variable(s), 46–50
   capture, 393–394
   declaration, 29, 31, 46–47, 48–50
   definition of the term, 28, 46
   dynamic initialization of, 47
   effectively final, 393–394
   enumeration, 268
   final, 149, 267
   instance. See Instance variables
   interface, 199, 206–208
   interface reference, 200–202, 206
   and JShell, 1246–1247
   loop control, 95, 96, 97, 98, 99
   member, 21
   object reference. See Object reference variables
   scope and lifetime of, 47–50
   temporary, 1252
   volatile, 323
VBox layout, 1168, 1186
Vector class, 528, 541, 560, 592, 593–597
   legacy methods, table of, 594–595
Version information, obtaining, 492
version( ), 489, 492
VetoableChangeListener interface, 1193, 1194
Viewport, scroll pane, 1044, 1045, 1147
visitFile( ), 746, 748
void, 27, 117
Void class, 485
volatile modifier, 322, 323
wait(), 187, 188, 255–256, 258–259, 262–264, 499, 905, 933, 935, 954
waitFor(), 448, 492
WAITING, 264
WALL_TIME, 625
walk(), 725
walkFileTree(), 746–748
Warth, Chris, 6
Watchable interface, 722
WeakHashMap class, 568
Web. See World Wide Web
Web browser, 757, 1201, 1202, 1205, 1206
executing applet in, 8, 11
Web server and servlets, 1202
Web Start. See Java Web Start
WebView class, 1186
weightx constraint field, 865, 866
weighty constraint field, 865, 866
while loop, 91–92
and break, 105
Whitespace, 34, 84
characters, 609
from a string, removing, 454
with keyword, 35, 410, 425
whois, 750, 754–756, 757
Wildcard arguments, 347–354, 368
bounded, 350–354
used in creating an array, 377
Window, AWT-based
class hierarchy, 804–805
close event, 787, 790, 795, 807
as an event source, 781, 782
frame. See Frame window
and graphics, 810
paint mode, setting the, 818–819
top-level, 805
Window class, 782, 804, 805, 807, 874
Window, Swing JFrame, 1018
windowActivated( ), 786
WindowAdapter class, 794, 795
windowClosed( ), 786
windowClosing( ), 786, 790, 794, 807, 809
WindowConstants interface, 1019
windowDeactivated( ), 786
windowDeiconified( ), 786
WindowEvent class, 773, 775, 781–782
WindowFocusListener interface, 783, 785, 795
windowGainedFocus( ), 785
windowIconified( ), 786
WindowListener interface, 783, 786, 790, 794, 795, 807, 809
windowLostFocus( ), 785
windowOpened( ), 786
Windows look and feel, 1013
WindowStateListener interface, 795
Work stealing, 941, 953
World Wide Web (WWW), 6, 7, 12, 18, 757
wrap( ), 720
Wrappers, primitive type, 276–279, 284, 340, 468–485
WRITE, 494
write( ), 307, 308, 312, 318–319, 681, 700, 711, 712, 721, 734, 735, 739
writeBoolean( ), 696, 712
writeDouble( ), 696, 712
Writer class, 307–308, 678, 679, 700, 701, 711
   methods defined by, table of, 700
writeExternal( ), 711
writeInt( ), 696, 712
writeObject( ), 711, 712, 715
writeTo( ), 688

X
XOR (exclusive OR) operator (^)
   bitwise, 68, 69, 70–71
   Boolean logical, 77, 78
XOR paint mode, 818–819
Y
Yellin, Frank, 6

Z
Zero crossing, 69
ZIP file format, 667
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