Java™ 2:
A Beginner’s Guide
Second Edition
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Java™ 2: A Beginner’s Guide

Second Edition

Herbert Schildt
About the Author

Herbert Schildt is the world’s leading programming author. He is an authority on the C, C++, Java, and C# languages, and is a master Windows programmer. His programming books have sold more than 3 million copies worldwide and have been translated into all major foreign languages. He is the author of numerous bestsellers, including Java 2: The Complete Reference, Java 2: A Beginner’s Guide, Java 2 Programmer’s Reference, C++: The Complete Reference, C: The Complete Reference, and C#: The Complete Reference. Schildt holds a master’s degree in computer science from the University of Illinois. He can be reached at his consulting office at (217) 586-4683.
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In the space of a few short years, Java went from relative obscurity to being the most important language of the Internet. The impact of Java cannot be understated. It transformed the Web into a highly interactive environment, setting a new standard in computer language design in the process. The innovative aspects of Java have already changed the course of programming well into the foreseeable future. Therefore, if Internet-based programming is in your future, you have chosen the right language to learn—and this book will help you learn it.

The purpose of this book is to teach you the fundamentals of Java programming. It uses a step-by-step approach complete with numerous examples, self-tests, and projects. It assumes no previous programming experience. The book starts with the basics, such as how to compile and run a Java program. It then discusses every keyword in the Java language. It concludes with some of Java’s most advanced features, such as multithreaded programming and creating applets. By the time you finish, you will have a firm grasp of the essentials of Java programming.

It is important to state at the outset that this book is just a starting point. Java is more than just the elements that define the language. Java also includes extensive libraries and tools that aid in the development of programs. Furthermore, Java provides a sophisticated set of libraries that handle the browser user interface. To be a top-notch Java programmer implies mastery of these areas, too. After completing this book you will have the knowledge to pursue any and all other aspects of Java.
How This Book Is Organized

This book presents an evenly paced tutorial in which each section builds upon the previous one. It contains 12 modules, each discussing an aspect of Java. This book is unique because it includes several special elements that reinforce what you are learning.

Critical Skills

Each module begins with a set of critical skills that you will be learning. The location of each skill is indicated within the module.

Mastery Check

Each module concludes with a Mastery Check, a list of questions that lets you test your knowledge. The answers are in Appendix A.

Progress Checks

At the end of each major section is a “Progress Check” that tests your understanding of the key points that were presented. The answers to these questions are at the bottom of the page.

Ask the Expert

Sprinkled throughout the book are “Ask the Expert” boxes. These contain additional information or interesting commentary about a topic. They use a question-and-answer format.

Projects

Each module contains one or more projects that show you how to apply what you are learning. These are real-world examples that you can use as starting points for your own programs.

No Previous Programming Experience Required

This book assumes no previous programming experience. Thus, if you have never programmed before, you can use this book. Of course, in this day and age, most readers will have at least a little prior programming experience. For many, this previous experience will be in C++. As you will learn, C++ and Java are related. Therefore, if you already know C++, then you will be able
to learn Java very easily. Since many readers will have some C++ experience, similarities between C++ and Java are pointed out from time to time throughout the book.

**Required Software**

To compile and run the programs in this book you will need the latest Java Software Developers Kit (SDK) from Sun, which at the time of this writing is Java 2, version 1.4. Instructions for obtaining the Java SDK are given in Module 1.

**Don’t Forget: Code on the Web**

Remember, the source code for all of the examples and projects in this book is available free of charge on the Web at [www.osborne.com](http://www.osborne.com).
For Further Study

*Java 2: A Beginner’s Guide* is your gateway to the Herb Schildt series of programming books. Here are some others that you will find of interest.

To learn more about Java programming, we recommend the following:

- *Java 2: The Complete Reference*
- *Java 2 Programmer’s Reference*

To learn about C++, you will find these books especially helpful.

- *C++: The Complete Reference*
- *Teach Yourself C++*
- *C++ from the Ground Up*
- *STL Programming from the Ground Up*
- *C/C++ Annotated Archives*

To learn about C#, we suggest the following Schildt books:

- *C#: A Beginner’s Guide*
- *C#: The Complete Reference*

If you want to learn more about the C language, then the following titles will be of interest.

- *C: The Complete Reference*
- *Teach Yourself C*

*When you need solid answers, fast, turn to Herbert Schildt, the recognized authority on programming.*
Module 1

Java Fundamentals

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The rise of the Internet and the World Wide Web have fundamentally reshaped computing. Only a few short years ago, the cyber landscape was dominated by stand-alone PCs. Today, nearly all PCs are connected to the Internet. The Internet, itself, was transformed—originally offering a convenient way to share files and information, today it is a vast, distributed computing universe. These changes have been as rapid as they have been profound, and in their wake, they gave rise to a new way to program: Java.

Java is the preeminent language of the Internet, but it is more than that. Java has revolutionized programming, changing the way that we think about both the form and the function of a program. To be a professional programmer today implies the ability to program in Java—it has become that important. In the course of this book, you will learn the skills needed to master it.

The purpose of this module is to introduce you to Java, including its history, its design philosophy, and several of its most important features. By far, the hardest thing about learning a programming language is the fact that no element exists in isolation. Instead, the components of the language work in conjunction with each other. This interrelatedness is especially pronounced in Java. In fact, it is difficult to discuss one aspect of Java without involving others. To help overcome this problem, this module provides a brief overview of several Java features, including the general form of a Java program, some basic control structures, and operators. It does not go into too many details but, rather, concentrates on the general concepts common to any Java program.

**CRITICAL SKILL**

1.1 The Origins of Java

Computer language innovation is driven forward by two factors: improvements in the art of programming and changes in the computing environment. Java is no exception. Building upon the rich legacy inherited from C and C++, Java adds refinements and features that reflect the current state of the art in programming. Responding to the rise of the online environment, Java offers features that streamline programming for a highly distributed architecture.

Java was conceived by James Gosling, Patrick Naughton, Chris Warth, Ed Frank, and Mike Sheridan at Sun Microsystems in 1991. This language was initially called “Oak” but was renamed “Java” in 1995. Somewhat surprisingly, the original impetus for Java was not the Internet! Instead, the primary motivation was the need for a platform-independent language that could be used to create software to be embedded in various consumer electronic devices, such as toasters, microwave ovens, and remote controls. As you can probably guess, many different types of CPUs are used as controllers. The trouble was that most computer languages are designed to be compiled for a specific target. For example, consider C++.

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, however, is that compilers are expensive and time-consuming to create. In an attempt to find a better solution, Gosling
and others worked on a portable, cross-platform language that could 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 emerged 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 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. 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 many types of computers, operating systems, and CPUs. What was once an irritating but a 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. This realization caused the focus of Java to switch from consumer electronics to Internet programming. So, while it was the desire for an architecture-neutral programming language that provided the initial spark, it was the Internet that ultimately led to Java’s large-scale success.

How Java Relates to C and C++

Java is directly related to both C and C++. Java inherits its syntax from C. Its object model is adapted from C++. Java’s relationship with C and C++ is important for several reasons. First, many programmers are familiar with the C/C++ syntax. This makes it easy for a C/C++ programmer to learn Java and, conversely, for a Java programmer to learn C/C++.

Second, Java’s designers did not “reinvent the wheel.” Instead, they further refined an already highly successful programming paradigm. The modern age of programming began with C. It moved to C++, and now to Java. By inheriting and building upon that rich heritage, Java provides a powerful, logically consistent programming environment that takes the best of the past and adds new features required by the online environment. Perhaps most important, because of their similarities, C, C++, and Java define a common, conceptual framework for the professional programmer. Programmers do not face major rifts when switching from one language to another.

One of the central design philosophies of both C and C++ is that the programmer is in charge! Java also inherits this philosophy. 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.

Java has one other attribute in common with C and C++: it 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. There is no better way to produce a top-flight professional programming
language.

Because of the similarities between Java and C++, especially their support for object-
oriented programming, it is tempting to think of Java as simply the “Internet version of C++.”
However, to do so would be a mistake. Java has significant practical and philosophical differences.
Although Java was influenced by C++, it is not an enhanced version of C++. For example, it is
neither upwardly nor downwardly compatible with C++. Of course, the similarities with C++
are significant, and if you are a C++ programmer, you will feel right at home with Java.
Another 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.

How Java Relates to C#

Recently a new language called C# has come on the scene. Created by Microsoft to support
its .NET Framework, C# is closely related to Java. In fact, many of C#’s features were directly
adapted from Java. Both Java and C# share the same general C++-style 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
means that if you already know C#, then learning Java will be especially easy. Conversely, if
C# is in your future, then your knowledge of Java will come in handy.

Given the similarity between Java and C#, one might naturally ask, “Will C# replace
Java?” The answer is No. Java and C# are optimized for two different types of computing
environments. Just as C++ and Java will co-exist for a long time to come, so will C# and Java.

Progress Check

1. Java is useful for the Internet because it can produce ____________ programs.

2. Java is the direct descendent of what languages?

1. Portable
2. C and C++
Java’s Contribution to the Internet

The Internet helped catapult Java to the forefront of programming, and Java, in turn, has had a profound effect on the Internet. The reason for this is quite simple: Java expands the universe of objects that can move about freely in cyberspace. In a network, there are two very broad categories of objects that are transmitted between the server and your personal computer: 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. However, a second type of object can be transmitted to your computer: a dynamic, self-executing program. Such a program is an active agent on the client computer, yet it is initiated by the server. For example, a program might be provided by the server to properly display the data that it is sending.

As desirable as dynamic, networked programs are, they also present serious problems in the areas of security and portability. Prior to Java, cyberspace was effectively closed to half of the entities that now live there. As you will see, Java addresses those concerns and, in doing so, has defined a new form of program: the applet.

Java Applets and Applications

Java can be used to create two types of programs: applications and applets. An application is a program that runs on your computer, under the operating system of that computer. An application created by Java is more or less like one created using any other type of computer language, such as Visual Basic or C++. When used to create applications, Java is not much different from any other computer language. Rather, it is Java’s ability to create applets that makes it important. An applet is an application designed to be transmitted over the Internet and executed by a Java-compatible Web browser. Although any computer language can be used to create an application, only Java can be used to create an applet. The reason is that Java solves two of the thorniest problems associated with applets: security and portability. Before continuing, let’s define what these two terms mean relative to the Internet.

Security

As you are almost certainly aware, every time you download a “normal” program, you are risking a viral infection. Prior to Java, most users did not download executable programs frequently, and those that did, scanned them for viruses prior to execution. Even so, most users still worried about the possibility of infecting their systems with a virus or allowing a malicious program to run wild in their systems. (A malicious 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.) Java answers these concerns by providing a firewall between a networked application and your computer.
When using a Java-compatible web browser, it is possible to safely download Java applets without fear of viral infection. The way that Java achieves this is by confining a Java program to the Java execution environment and not allowing it access to other parts of the computer. (You will see how this is accomplished, shortly.) Frankly, the ability to download applets with confidence that no harm will be done to the client computer is the single most important aspect of Java.

Portability

As discussed earlier, many types of computers and operating systems are connected to the Internet. For programs to be dynamically downloaded to all of the various types of platforms, some means of generating portable executable code is needed. As you will soon see, the same mechanism that helps ensure security also helps create portability. Indeed, Java’s solution to these two problems is both elegant and efficient.

**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). That is, in its standard form, the Java Virtual Machine is an *interpreter for bytecode*. This may come as a bit of a surprise. As you know, most modern languages, such as C++, are designed to be compiled, not interpreted—mostly because of performance concerns. However, the fact that a Java program is executed by the JVM helps solve the major problems associated with downloading programs over the Internet. Here is why.

Translating a Java program into bytecode makes it much easier to run a program in a wide variety of environments. The reason is straightforward: only the Java Virtual Machine 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 that although the details of the JVM will differ from platform to platform, all interpret 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 interpretation of bytecode is the easiest way to create truly portable programs.

The fact that a Java program is interpreted also helps make it secure. Because the execution of every Java program is under the control of the JVM, the JVM can contain the program and prevent it from generating side effects outside the system. Safety is also enhanced by certain restrictions that exist in the Java language.

When a program is interpreted, it generally runs substantially slower than the same program would run if compiled to executable code. However, with Java, the differential between the
two is not so great. The use of bytecode makes it possible for the Java run-time system to execute programs much faster than you might expect.

Although Java was designed for interpretation, there is technically nothing about Java that prevents on-the-fly compilation of bytecode into native code. Along these lines, Sun supplies a JIT (Just In Time) compiler for bytecode. When the JIT compiler is part of the JVM, it compiles bytecode into executable code in real time, on a piece-by-piece, demand basis. It is important to understand that it is not possible to compile an entire Java program into executable code all at once because Java performs various checks that can be performed only at run time. Instead, the JIT compiles code as it is needed, during execution. The just-in-time approach still yields a significant performance boost, though. Even when dynamic compilation is applied to bytecode, the portability and safety features will still apply, because the run-time system (which performs the compilation) will still be in charge of the execution environment. Whether your Java program is actually interpreted in the traditional way, or compiled on-the-fly, its functionality is the same.

**Critical Skill 1.4 The Java Buzzwords**

No overview of Java 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 played an important role in molding the final form of the language. The key considerations were summed up by the Java design team in the following list of buzzwords.

<table>
<thead>
<tr>
<th>Buzzword</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>Java has a concise, cohesive set of features that makes it easy to learn and use.</td>
</tr>
<tr>
<td>Secure</td>
<td>Java provides a secure means of creating Internet applications.</td>
</tr>
<tr>
<td>Portable</td>
<td>Java programs can execute in any environment for which there is a Java run-time system.</td>
</tr>
<tr>
<td>Object-oriented</td>
<td>Java embodies the modern, object-oriented programming philosophy.</td>
</tr>
<tr>
<td>Robust</td>
<td>Java encourages error-free programming by being strictly typed and performing run-time checks.</td>
</tr>
<tr>
<td>Multithreaded</td>
<td>Java provides integrated support for multithreaded programming.</td>
</tr>
<tr>
<td>Architecture-neutral</td>
<td>Java is not tied to a specific machine or operating system architecture.</td>
</tr>
<tr>
<td>Interpreted</td>
<td>Java supports cross-platform code through the use of Java bytecode.</td>
</tr>
<tr>
<td>High performance</td>
<td>The Java bytecode is highly optimized for speed of execution.</td>
</tr>
<tr>
<td>Distributed</td>
<td>Java was designed with the distributed environment of the Internet in mind.</td>
</tr>
<tr>
<td>Dynamic</td>
<td>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.</td>
</tr>
</tbody>
</table>
Progress Check

1. What is an applet?
2. What is Java bytecode?
3. The use of bytecode helps solve what two Internet programming problems?

CRITICAL SKILL

Object-Oriented Programming

At the center of Java is object-oriented programming (OOP). The object-oriented methodology is inseparable from Java, and all Java programs are, to at least some extent, object-oriented. Because of OOP’s importance to Java, it is useful to understand OOP’s basic principles before you write even a simple Java program.

OOP is a powerful way to approach the job of programming. Programming methodologies have changed dramatically since the invention of the computer, primarily to accommodate the increasing complexity of programs. For example, when computers were first invented, programming was done by toggling in the binary machine instructions using the computer’s 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, 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. Although FORTRAN was a very impressive first step, it is hardly a language that encourages clear, easy-to-understand programs.

The 1960s gave birth to structured programming. This is the method encouraged by languages such as C and Pascal. The use of structured languages made it possible to write moderately complex programs fairly easily. Structured languages are characterized by their support for stand-alone subroutines, local variables, rich control constructs, and their lack of reliance upon the GOTO. Although structured languages are a powerful tool, even they reach their limit when a project becomes too large.

Consider this: At each milestone in the development of programming, techniques and tools were created to allow the programmer to deal with increasingly greater complexity. Each step of the way, the new approach took the best elements of the previous methods and moved forward. Prior to the invention of OOP, many projects were nearing (or exceeding) the point where the structured approach no longer works. Object-oriented methods were created to help programmers break through these barriers.

Object-oriented programming took the best ideas of structured programming and combined them with several new concepts. The result was a different way of organizing a program. In the most general sense, a program can be organized in one of two ways: around its code (what is happening) or around its data (who is being affected). Using only structured programming techniques, programs are typically organized around code. This approach can be thought of as “code acting on data.”

Object-oriented programs work the other way around. They are organized around data, with the key principle being “data controlling access to code.” In an object-oriented language, you define the data and the routines that are permitted to act on that data. Thus, a data type defines precisely what sort of operations can be applied to that data.

To support the principles of object-oriented programming, all OOP languages, including Java, have three traits in common: encapsulation, polymorphism, and inheritance. Let’s examine each.

**Encapsulation**

*Encapsulation* is a programming mechanism that binds together code and the data it manipulates, and that keeps both safe from outside interference and misuse. In an object-oriented language, code and data can be bound together in such a way that a self-contained *black box* is created. Within the box are all necessary data and code. When code and data are linked together in this fashion, an object is created. In other words, an object is the device that supports encapsulation.

Within an object, code, data, or both may be *private* to that object or *public*. Private code or data is known to and accessible by only another part of the object. That is, private code or data cannot be accessed by a piece of the program that exists outside the object. When code
or data is public, other parts of your program can access it even though it is defined within an object. Typically, the public parts of an object are used to provide a controlled interface to the private elements of the object.

Java’s basic unit 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 form of an object. It specifies both the data and the code that will operate on that data. Java uses a class specification to construct objects. Objects are instances of a class. Thus, a class is essentially a set of plans that specify how to build an object.

The code and data that constitute a class 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. Method is Java’s term for a subroutine. 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.

**Polymorphism**

Polymorphism (from the Greek, meaning “many forms”) is the quality that allows one interface to access a general class of actions. The specific action is determined by the exact nature of the situation. A simple example of polymorphism is found in the steering wheel of an automobile. The steering wheel (i.e., the interface) is the same no matter what type of actual steering mechanism is used. That is, the steering wheel works the same whether your car has manual steering, power steering, or rack-and-pinion steering. Therefore, once you know how to operate the steering wheel, you can drive any type of car.

The same principle can also apply to programming. For example, consider a stack (which is a first-in, last-out list). You might have a program that requires three different types of stacks. One stack is used for integer values, one for floating-point values, and one for characters. In this case, 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 create one general set of stack routines that works for all three specific situations. This way, once you know how to use one stack, you can use them all.

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. Polymorphism 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 (i.e., method) as it applies to each situation. You, the programmer, don’t need to do this selection manually. You need only remember and utilize the general interface.

**Inheritance**

Inheritance is the process by which one object can acquire the properties of another object. This is important because it supports the concept of hierarchical classification. If you think
about it, most knowledge is made manageable by hierarchical (i.e., top-down) classifications. For example, a Red Delicious apple is part of the classification apple, which in turn is part of the fruit class, which is under the larger class food. That is, the food class possesses certain qualities (edible, nutritious, etc.) which also, logically, apply to its subclass, fruit. In addition to these qualities, the fruit class has specific characteristics (juicy, sweet, etc.) that distinguish it from other food. The apple class defines those qualities specific to an apple (grows on trees, not tropical, etc.). A Red Delicious apple would, in turn, inherit all the qualities of all preceding classes, and would define only those qualities that make it unique.

Without the use of hierarchies, each object would have to explicitly define all of its characteristics. Using 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.

Progress Check

1. Name the principles of OOP.

2. What is the basic unit of encapsulation in Java?

Ask the Expert

Q: You state that object-oriented programming is an effective way to manage large programs. However, it seems that it might add substantial overhead to relatively small ones. Since you say that all Java programs are, to some extent, object-oriented, does this impose a penalty for smaller programs?

A: No. As you will see, for small programs, Java’s object-oriented features are nearly transparent. Although it is true that Java follows a strict object model, you have wide latitude as to the degree to which you employ it. For smaller programs, their “object-orientedness” is barely perceptible. As your programs grow, you will integrate more object-oriented features effortlessly.

1. Encapsulation, polymorphism, and inheritance.
2. The class.
Obtaining the Java Software Developer’s Kit

Now that the theoretical underpinning of Java has been explained, it is time to start writing Java programs. Before you can compile and run those programs, however, you must have a Java development system installed on your computer. The one used by this book is the standard Java SDK (Java Software Developer’s Kit), which is available from Sun Microsystems. Several other Java development packages are available from other companies, but we will be using the SDK because it is available to all readers. It also constitutes the final authority on what is and isn’t proper Java. At the time of this writing, the current release of the Java SDK is the Java 2 Platform Standard Edition version 1.4 (J2SE v1.4). However, most of the material in this book will work with any modern version of Java.

The SDK can be downloaded free of charge from www.java.sun.com. Just go to the download page and follow the instructions for the type of computer that you have. After you have installed the SDK, you will be ready to compile and run programs. The SDK supplies two primary programs. The first is javac.exe, which is the Java compiler. The second is java.exe, which is the standard Java interpreter, and is also referred to as the application launcher.

One other point: the Java SDK runs in the command prompt environment. It is not a windowed application.

Critical skill

A First Simple Program

Let’s start by compiling and running the short sample program shown here.

```java
/*
 * This is a simple Java program.

 Call this file Example.java.
 */

class Example {
    // A Java program begins with a call to main().
    public static void main(String args[]) {
        System.out.println("Java drives the Web.");
    }
}
```

You will follow these three steps:

1. Enter the program.
2. Compile the program.
3. Run the program.
Entering the Program

The programs shown in this book are available from Osborne’s Web site: www.osborne.com. However, if you want to enter the programs by hand, you are free to do so. In this case, you must enter the program into your computer using a text editor, not a word processor. Word processors typically store format information along with text. This format information will confuse the Java compiler. If you are using a Windows platform, you can use WordPad or any other programming editor that you like.

For most computer languages, the name of the file that holds the source code to a program is arbitrary. 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 one or more class definitions. The Java compiler requires that a source file use the .java filename extension. Notice that the file extension is four characters long. As you might guess, your operating system must be capable of supporting long filenames. This means that Windows 95, 98, NT, XP, and 2000 work just fine, but Windows 3.1 doesn’t.

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 that 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. Remember, bytecode is not executable code. Bytecode must be executed by a Java Virtual Machine. Thus, the output of javac is not code that can be directly executed.

To actually run the program, you must use the Java interpreter, 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:

Java drives the Web.
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 the Java interpreter as just shown, you are actually specifying the name of the class that you want the interpreter 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.

The First Sample Program Line by Line

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. As mentioned, the class is Java’s basic unit of encapsulation. Example is the name of the class. The class definition begins with the opening curly brace ( { ) and ends with the closing curly brace ( } ). The elements between the two braces are members of the class. 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
// A Java program begins with a call to main().
```
This is the second type of comment supported by Java. A single-line comment begins with a // 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 next line of code is shown here:

```java
public static void main (String args[]) {

This line begins the main() method. As mentioned earlier, in Java, a subroutine is called a method. As the comment preceding it suggests, this is the line at which the program will begin executing. All Java applications begin execution by calling main(). (This is just like C/C++/C#.) The exact meaning of each part of this line cannot be given now, since it involves a detailed understanding of several other of Java’s features. However, since many of the examples in this book will use this line of code, let’s take a brief look at each part now.

The public keyword is an access specifier. An access specifier determines how other parts of the program can access the members of the class. When a class member is preceded by public, then that member can 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 before an object of the class has been created. This is necessary since main() is called by the Java interpreter 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 modules.

As stated, main() is the method called when a Java application begins. 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 no parameters are required for a given method, you still need to include the empty parentheses. In main() there is only one parameter, String args[ ], which declares a parameter named args. This is an array of objects of type String. (Arrays are collections of similar objects.) Objects of type String store sequences of characters. 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 included in a method will occur between the method’s opening curly brace and its closing curly brace.

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

System.out.println("Java drives the Web.");

This line outputs the string "Java drives the Web." 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. Thus, System.out is an object that encapsulates console output. The fact that Java uses an object to define console output is further evidence of its object-oriented nature.

As you have probably guessed, console output (and input) is not used frequently in real-world Java programs and applets. Since most modern computing environments are windowed and graphical in nature, console I/O is used mostly for simple utility programs and for demonstration programs. 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. All statements in Java end with a semicolon. The reason that the other lines in the program do not end in a semicolon is that they are not, technically, statements.

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

One last point: Java is case sensitive. Forgetting this can cause you serious problems. For example, if you accidentally type Main instead of main, or PrintLn instead of println, the preceding program will be incorrect. Furthermore, although the Java compiler will compile classes that do not contain a main( ) method, it has no way to execute them. So, if you had mistyped main, the compiler would still compile your program. However, the Java interpreter would report an error because it would be unable to find the main( ) method.

Progress Check

1. Where does a Java program begin execution?

2. What does System.out.println( ) do?

3. What is the name of the SDK Java compiler? Of the Java interpreter?

1. main( )
2. Outputs information to the console
3. The standard Java compiler is javac.exe; the interpreter is java.exe
Handling Syntax Errors

If you have not yet done so, enter, compile, and run the preceding program. As you may know from your previous programming experience, it is quite easy to accidentally type something incorrectly when entering code into your computer. Fortunately, if you enter something incorrectly into your program, the compiler will report a syntax error message when it tries to compile it. The Java compiler attempts to make sense out of your source code no matter what you have written. For this reason, the error that is reported may not always reflect the actual cause of the problem. In the preceding program, for example, an accidental omission of the opening curly brace after the main() method causes the compiler to report the following sequence of errors.

Example.java:8: ';' expected
   Public static void main(String args[])
        ^
Example.java:11 'class' or 'interface' expected
 )
 ^
Example.java:13: 'class' or 'interface' expected
 ^
Example.java:8: missing method body, or declare abstract
   Public static void main(String args[])
        ^

Clearly, the first error message is completely wrong because what is missing is not a semicolon, but a curly brace.

The point of this discussion is that when your program contains a syntax error, you shouldn’t necessarily take the compiler’s messages at face value. The messages may be misleading. You may need to “second-guess” an error message in order to find the real problem. Also, look at the last few lines of code in your program that precede the line being flagged. Sometimes an error will not be reported until several lines after the point at which the error actually occurred.

CRITICAL SKILL

A Second Simple Program

Perhaps no other construct is as important to a programming language as the assignment of a value to a variable. A variable is a named memory location that can be assigned a value. Further, the value of a variable can be changed during the execution of a program. That is, the content of a variable is changeable, not fixed.
The following program creates two variables called `var1` and `var2`.

```java
/*
This demonstrates a variable.

Call this file Example2.java.
*/
class Example2 {
    public static void main(String args[]) {
        int var1; // this declares a variable
        int var2; // this declares another variable

        var1 = 1024; // this assigns 1024 to var1
        System.out.println("var1 contains " + var1);

        var2 = var1 / 2;
        System.out.print("var2 contains var1 / 2: ");
        System.out.println(var2);
    }
}
```

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

```
var1 contains 1024
var2 contains var1 / 2: 512
```

This program introduces several new concepts. First, the statement

```java
int var1; // this declares a variable
```

declares a variable called `var1` of type integer. In Java, all variables must be declared before they are used. Further, the type of values that the variable can hold must also be specified. This is called the type of the variable. In this case, `var1` can hold integer values. These are whole number values. In Java, to declare a variable to be of type integer, precede its name with the keyword `int`. Thus, the preceding statement declares a variable called `var1` of type `int`.

The next line declares a second variable called `var2`.

```java
int var2; // this declares another variable
```

Notice that this line uses the same format as the first line except that the name of the variable is different.
In general, to declare a variable you will use a statement like this:

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

Here, `type` specifies the type of variable being declared, and `var-name` is the name of the variable. In addition to `int`, Java supports several other data types.

The following line of code assigns `var1` the value 1024:

```java
var1 = 1024; // this assigns 1024 to var1
```

In Java, the assignment operator is the single equal sign. It copies the value on its right side into the variable on its left.

The next line of code outputs the value of `var1` preceded by the string "var1 contains ":

```java
System.out.println("var1 contains " + var1);
```

In this statement, the plus sign causes the value of `var1` to be displayed after the string that precedes it. This approach can be generalized. Using the `+` operator, you can chain together as many items as you want within a single `println()` statement.

The next line of code assigns `var2` the value of `var1` divided by 2:

```java
var2 = var1 / 2;
```

This line divides the value in `var1` by 2 and then stores that result in `var2`. Thus, after the line executes, `var2` will contain the value 512. The value of `var1` will be unchanged. Like most other computer languages, Java supports a full range of arithmetic operators, including those shown here:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Addition</td>
</tr>
<tr>
<td>-</td>
<td>Subtraction</td>
</tr>
<tr>
<td>*</td>
<td>Multiplication</td>
</tr>
<tr>
<td>/</td>
<td>Division</td>
</tr>
</tbody>
</table>

Here are the next two lines in the program:

```java
System.out.print("var2 contains var1 / 2: ");
System.out.println(var2);
```

Two new things are occurring here. First, the built-in method `print()` is used to display the string "var2 contains var1 / 2: ". This string is not followed by a new line. 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 new line after each call. Second, in the call to `println()`,
notice that var2 is used by itself. Both print() and println() can be used to output values of any of Java’s built-in types.

One more point about declaring variables before we move on: It is possible to declare two or more variables using the same declaration statement. Just separate their names by commas. For example, var1 and var2 could have been declared like this:

```java
int var1, var2; // both declared using one statement
```

## Another Data Type

In the preceding program, a variable of type int was used. However, a variable of type int can hold only whole numbers. Thus, it cannot be used when a fractional component is required. For example, an int variable can hold the value 18, but not the value 18.3. Fortunately, int is only one of several data types defined by Java. To allow numbers with fractional components, Java defines two floating-point types: float and double, which represent single- and double-precision values, respectively. Of the two, double is the most commonly used.

To declare a variable of type double, use a statement similar to that shown here:

```java
double x;
```

Here, x is the name of the variable, which is of type double. Because x has a floating-point type, it can hold values such as 122.23, 0.034, or −19.0.

To better understand the difference between int and double, try the following program:

```java
/*
 * This program illustrates the differences between int and double.
 * Call this file Example3.java.
 */
class Example3 {
    public static void main(String args[]) {
        int var; // this declares an int variable
        double x; // this declares a floating-point variable

        var = 10; // assign var the value 10
        x = 10.0; // assign x the value 10.0

        System.out.println("Original value of var: " + var);
        System.out.println("Original value of x: " + x);
    }
}
```
System.out.println(); // print a blank line

// now, divide both by 4
var = var / 4;
x = x / 4;

System.out.println("var after division: " + var);
System.out.println("x after division: " + x);
}

The output from this program is shown here:

Original value of var: 10
Original value of x: 10.0

var after division: 2 ➡️ Fractional component lost
x after division: 2.5 ➡️ Fractional component preserved

As you can see, when var is divided by 4, a whole-number division is performed, and the outcome is 2—the fractional component is lost. However, when x is divided by 4, the fractional component is preserved, and the proper answer is displayed.

There is one other new thing to notice in the program. To print a blank line, simply call println() without any arguments.

Ask the Expert

Q: Why does Java have different data types for integers and floating-point values? That is, why aren’t all numeric values just the same type?

A: Java supplies different data types so that you can write efficient programs. For example, integer arithmetic is faster than floating-point calculations. Thus, if you don’t need fractional values, then you don’t need to incur the overhead associated with types float or double. Second, the amount of memory required for one type of data might be less than that required for another. By supplying different types, Java enables you to make best use of system resources. Finally, some algorithms require (or at least benefit from) the use of a specific type of data. In general, Java supplies a number of built-in types to give you the greatest flexibility.
Converting Gallons to Liters

Although the preceding sample programs illustrate several important features of the Java language, they are not very useful. Even though you do not know much about Java at this point, you can still put what you have learned to work to create a practical program. In this project, we will create a program that converts gallons to liters.

The program will work by declaring two `double` variables. One will hold the number of the gallons, and the second will hold the number of liters after the conversion. There are 3.7854 liters in a gallon. Thus, to convert gallons to liters, the gallon value is multiplied by 3.7854. The program displays both the number of gallons and the equivalent number of liters.

Step by Step

1. Create a new file called `GalToLit.java`.

2. Enter the following program into the file:

   ```java
   /*
   Project 1-1
   This program converts gallons to liters.
   Call this program GalToLit.java.
   */
   class GalToLit {
     public static void main(String args[]) {
       double gallons; // holds the number of gallons
       double liters;  // holds conversion to liters

       gallons = 10; // start with 10 gallons
       liters = gallons * 3.7854; // convert to liters

       System.out.println(gallons + " gallons is " + liters + " liters.");
     }
   }
   
3. Compile the program using the following command line:

   `C>javac GalToLit.java`

4. Run the program using this command:

   `C>java GalToLit`

   You will see this output:

   10.0 gallons is 37.854 liters.`
5. As it stands, this program converts 10 gallons to liters. However, by changing the value assigned to *gallons*, you can have the program convert a different number of gallons into its equivalent number of liters.

**Progress Check**

1. What is Java’s keyword for the integer data type?
2. What is *double*?

---

**CRITICAL SKILL**

### Two Control Statements

Inside a method, execution proceeds from one statement to the next, top to bottom. However, it is possible to alter this flow through the use of the various program control statements supported by Java. Although we will look closely at control statements later, two are briefly introduced here because we will be using them to write sample programs.

**The if Statement**

You can selectively execute part of a program through the use of Java’s conditional statement: the *if*. The Java *if* statement works much like the IF statement in any other language. For example, it is syntactically identical to the *if* statements in C, C++, and C#. Its simplest form is shown here:

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

Here, *condition* is a Boolean expression. If *condition* is true, then the statement is executed. If *condition* is false, then the statement is bypassed. Here is an example:

```java
if(10 < 11) System.out.println("10 is less than 11");
```

In this case, since 10 is less than 11, the conditional expression is true, and `println()` will execute. However, consider the following:

```java
if(10 < 9) System.out.println("this won't be displayed");
```

In this case, 10 is not less than 9. Thus, the call to `println()` will not take place.

1. *int*
2. The keyword for the *double* floating-point data type.
Java defines a full complement of relational operators that may be used in a conditional expression. They are shown here:

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

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

Here is a program that illustrates the `if` statement:

```java
/*
   Demonstrate the if.

   Call this file IfDemo.java.
*/
class IfDemo {
   public static void main(String args[]) {
      int a, b, c;

      a = 2;
      b = 3;

      if(a < b) System.out.println("a is less than b");

      // this won't display anything
      if(a == b) System.out.println("you won't see this");

      System.out.println();

      c = a - b; // c contains -1
      System.out.println("c contains -1");
      if(c >= 0) System.out.println("c is non-negative");
      if(c < 0) System.out.println("c is negative");

      System.out.println();

      c = b - a; // c now contains 1
      System.out.println("c contains 1");
```
if(c >= 0) System.out.println("c is non-negative");
if(c < 0) System.out.println("c is negative");
)
}

The output generated by this program is shown here:

a is less than b
c contains -1
c is negative
c contains 1
c is non-negative

Notice one other thing in this program. The line

int a, b, c;

declares three variables, a, b, and c, by use of a comma-separated list. As mentioned earlier, when you need two or more variables of the same type, they can be declared in one statement. Just separate the variable names by commas.

The for Loop
You can repeatedly execute a sequence of code by creating a loop. Java supplies a powerful assortment of loop constructs. The one we will look at here is the for loop. If you are familiar with C, C++, or C#, then you will be pleased to know that the for loop in Java works the same way it does in those languages. If you don’t know any of those languages, the for loop is still easy to use. 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, 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:

/*
   Demonstrate the for loop.

   Call this file ForDemo.java.
class ForDemo {
    public static void main(String args[]) {
        int count;

        for(count = 0; count < 5; count = count+1) {
            System.out.println("This is count: " + count);
        }

        System.out.println("Done!");
    }
}

The output generated by the program is shown here:

This is count: 0
This is count: 1
This is count: 2
This is count: 3
This is count: 4
Done!

In this example, count is the loop control variable. It is set to zero in the initialization portion of the for. At the start of each iteration (including the first one), the conditional test count < 5 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. This process continues until the conditional test is false, at which point execution picks up at the bottom of the loop.

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:

count = count + 1;

The reason is that Java includes a special increment operator that 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:

count++;

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

for(count = 0; count < 5; count++)
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.

Progress Check

1. What does the if statement do?
2. What does the for statement do?
3. What are Java’s relational operators?

CRITICAL SKILL

1.9 Create Blocks of Code

Another key element of Java is the code block. A code block is a grouping of two or more statements. 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(w < h) {
    v = w * h;
    w = 0;
}
```

Here, if w is less than h, 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. Code blocks allow many algorithms to be implemented with greater clarity and efficiency.

1. The if is Java’s conditional statement.
2. The for is one of Java’s loop statements.
3. The relational operators are ==, !, <, >, <=, and >=.
Here is a program that uses a block of code to prevent a division by zero:

```java
/*
   Demonstrate a block of code.

   Call this file BlockDemo.java.
*/
class BlockDemo {
    public static void main(String args[]) {
        double i, j, d;

        i = 5;
        j = 10;

        // the target of this if is a block
        if(i != 0) {
            System.out.println("i does not equal zero");
            d = j / i;
            System.out.print("j / i is " + d);
        }
    }
}
```

The output generated by this program is shown here:

```
i does not equal zero
j / i is 2.0
```

In this case, the target of the `if` statement is a block of code and not just a single statement. If the condition controlling the `if` is true (as it is in this case), the three statements inside the block will be executed. Try setting `i` to zero and observe the result.

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.

### Ask the Expert

**Q:** Does the use of a code block introduce any run-time inefficiencies? In other words, does Java actually execute the `{ and `}?  

**A:** No. Code blocks do not add any overhead whatsoever. In fact, because of their ability to simplify the coding of certain algorithms, their use generally increases speed and efficiency. Also, the `{ and `} exist only in your program’s source code. Java does not, per se, execute the `{ or `}.  

Team-Fly®
Semicolons and Positioning

In Java, the semicolon is a statement terminator. That is, each individual statement must be ended with a semicolon. It indicates the end of one logical entity.

As you know, a block is a set of logically connected statements that are surrounded by opening and closing braces. A block is not terminated with a semicolon. Since a block is a group of statements, with a semicolon after each statement, it makes sense that a block is not terminated by a semicolon; instead, the end of the block is indicated by the closing brace.

Java does not recognize the end of the line as a terminator. For this reason, it does not matter where on a line you put a statement. For example,

```java
x = y;
y = y + 1;
System.out.println(x + " " + y);
```

is the same as the following, to Java.

```java
x = y; y = y + 1; System.out.println(x + " " + y);
```

Furthermore, the individual elements of a statement can also be put on separate lines. For example, the following is perfectly acceptable:

```java
System.out.println("This is a long line of output" +
                   + x + y + z +
                   + "more output");
```

Breaking long lines in this fashion is often used to make programs more readable. It can also help prevent excessively long lines from wrapping.

Indentation Practices

You may have noticed in the previous examples that certain statements were indented. Java is a free-form language, meaning that it does not matter where you place statements relative to each other on a line. However, over the years, a common and accepted indentation style has developed that allows for very readable programs. This book follows that style, and it is recommended that you do so as well. Using this style, you indent one level after each opening brace, and move back out one level after each closing brace. Certain statements encourage some additional indenting; these will be covered later.
Progress Check

1. How is a block of code created? What does it do?
2. In Java, statements are terminated by a ____________.
3. All Java statements must start and end on one line. True or False?

Project 1-2 Improving the Gallons-to-Liters Converter

You can use the for loop, the if statement, and code blocks to create an improved version of the gallons-to-liters converter that you developed in the first project. This new version will print a table of conversions, beginning with 1 gallon and ending at 100 gallons. After every 10 gallons, a blank line will be output. This is accomplished through the use of a variable called counter that counts the number of lines that have been output. Pay special attention to its use.

Step by Step

1. Create a new file called GalToLitTable.java.
2. Enter the following program into the file.

```java
/*
Project 1-2

This program displays a conversion table of gallons to liters.

Call this program "GalToLitTable.java".
*/

class GalToLitTable {
    public static void main(String args[]) {
        double gallons, liters;
        int counter = 0; // Line counter is initially set to zero.
        for(gallons = 1; gallons <= 100; gallons++) {
            liters = gallons * 3.7854; // convert to liters
            counter = counter + 1;
            if (counter % 10 == 0) {
                System.out.println();
            }
        }
    }
}
```

1. A block is started by a {. It is ended by a }. A block creates a logical unit of code.
2. Semicolon.
3. False.
System.out.println(gallons + " gallons is " +
         liters + " liters.");

    // every 10th line, print a blank line
    if(counter == 10) {
        System.out.println();
        counter = 0; // reset the line counter
    }

3. Compile the program using the following command line:
   C>javac GalToLitTable.java

4. Run the program using this command:
   C>java GalToLitTable

Here is a portion of the output that you will see:

    1.0 gallons is 3.7854 liters.
    2.0 gallons is 7.5708 liters.
    3.0 gallons is 11.356200000000001 liters.
    4.0 gallons is 15.1416 liters.
    5.0 gallons is 18.927 liters.
    6.0 gallons is 22.712400000000002 liters.
    7.0 gallons is 26.4978 liters.
    8.0 gallons is 30.2832 liters.
    9.0 gallons is 34.0686 liters.
   10.0 gallons is 37.854 liters.

   11.0 gallons is 41.6394 liters.
   12.0 gallons is 45.424800000000005 liters.
   13.0 gallons is 49.2102 liters.
   14.0 gallons is 52.9956 liters.
   15.0 gallons is 56.781 liters.
   16.0 gallons is 60.5664 liters.
   17.0 gallons is 64.3518 liters.
   18.0 gallons is 68.1372 liters.
   19.0 gallons is 71.9226 liters.
   20.0 gallons is 75.708 liters.

   21.0 gallons is 79.493400000000001 liters.
   22.0 gallons is 83.2788 liters.
   23.0 gallons is 87.0642 liters.

(continued)
24.0 gallons is 90.84960000000001 liters.
25.0 gallons is 94.635 liters.
26.0 gallons is 98.4204 liters.
27.0 gallons is 102.2058 liters.
28.0 gallons is 105.9912 liters.
29.0 gallons is 109.7766 liters.
30.0 gallons is 113.562 liters.

**CRITICAL SKILL**

### 1.11 The Java Keywords

Forty-nine keywords are currently defined in the Java language (see Table 1-1). These keywords, combined with the syntax of the operators and separators, form the definition of the Java language. These keywords cannot be used as names for a variable, class, or method.

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 1-1.

The `assert` keyword is quite new. It was added in 2002 when Java 2, version 1.4 was released. 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.

**CRITICAL SKILL**

### 1.12 Identifiers in Java

In Java an identifier is a name given to a method, a variable, or any other user-defined item. Identifiers can be from one to several characters long. Variable names may start with any letter of the alphabet, an underscore, or a dollar sign. Next may be either a letter, a digit, a dollar sign, or an underscore. The underscore can be used to enhance the readability of a variable

<table>
<thead>
<tr>
<th>abstract</th>
<th>assert</th>
<th>boolean</th>
<th>break</th>
<th>byte</th>
<th>case</th>
</tr>
</thead>
<tbody>
<tr>
<td>catch</td>
<td>char</td>
<td>class</td>
<td>const</td>
<td>continue</td>
<td>default</td>
</tr>
<tr>
<td>do</td>
<td>double</td>
<td>else</td>
<td>extends</td>
<td>final</td>
<td>finally</td>
</tr>
<tr>
<td>float</td>
<td>for</td>
<td>goto</td>
<td>if</td>
<td>implements</td>
<td>import</td>
</tr>
<tr>
<td>instanceof</td>
<td>int</td>
<td>interface</td>
<td>long</td>
<td>native</td>
<td>new</td>
</tr>
<tr>
<td>package</td>
<td>private</td>
<td>protected</td>
<td>public</td>
<td>return</td>
<td>short</td>
</tr>
<tr>
<td>static</td>
<td>strictfp</td>
<td>super</td>
<td>switch</td>
<td>synchronized</td>
<td>this</td>
</tr>
<tr>
<td>throw</td>
<td>throws</td>
<td>transient</td>
<td>try</td>
<td>void</td>
<td>volatile</td>
</tr>
<tr>
<td>while</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 1-1: The Java Keywords*
name, as in **line_count**. Uppercase and lowercase are different; that is, to Java, **myvar** and **MyVar** are separate names. Here are some examples of acceptable identifiers:

<table>
<thead>
<tr>
<th>Test</th>
<th>x</th>
<th>y2</th>
<th>MaxLoad</th>
</tr>
</thead>
<tbody>
<tr>
<td>$up</td>
<td>_top</td>
<td>my_var</td>
<td>sample23</td>
</tr>
</tbody>
</table>

Remember, you can’t start an identifier with a digit. Thus, **12x** is invalid, for example.

You cannot use any of the Java keywords as identifier names. Also, you should not assign the name of any standard method, such as **println** to an identifier. Beyond these two restrictions, good programming practice dictates that you use identifier names that reflect the meaning or usage of the items being named.

**Progress Check**

1. Which is the keyword: **for**, **For**, or **FOR**?
2. A Java identifier can contain what type of characters?
3. Are **index21** and **Index21** the same identifier?

**The Java Class Libraries**

The sample programs shown in this module make use of two of Java’s built-in methods: **println()** and **print()**. These methods are members of the **System** class, which 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 windowed output. 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 this book, various elements of the standard library classes and methods are described. However, the Java library is something that you will also want to explore more on your own.

1. The keyword is **for**. In Java, all keywords are in lowercase.
2. Letters, digits, the underscore, and the $.
3. No; Java is case sensitive.
Module 1 Mastery Check

1. What is bytecode and why is it important to Java’s use for Internet programming?
2. What are the three main principles of object-oriented programming?
3. Where do Java programs begin execution?
4. What is a variable?
5. Which of the following variable names is invalid?
   A. count
   B. $count
   C. count27
   D. 67count
6. How do you create a single-line comment? How do you create a multiline comment?
7. Show the general form of the if statement. Show the general form of the for loop.
8. How do you create a block of code?
9. The moon’s gravity is about 17 percent that of earth’s. Write a program that computes your effective weight on the moon.
10. Adapt Project 1-2 so that it prints a conversion table of inches to meters. Display 12 feet of conversions, inch by inch. Output a blank line every 12 inches. (One meter equals approximately 39.37 inches.)
11. If you make a typing mistake when entering your program, what sort of error will result?
12. Does it matter where on a line you put a statement?
Module 2

Introducing Data Types and Operators

CRITICAL SKILLS

2.1 Know Java’s simple types
2.2 Use literals
2.3 Initialize variables
2.4 Know the scope rules of variables within a method
2.5 Use the arithmetic operators
2.6 Use the relational and logical operators
2.7 Understand the assignment operators
2.8 Use shorthand assignments
2.9 Understand type conversion in assignments
2.10 Cast incompatible types
2.11 Understand type conversion in expressions
At the foundation of any programming language are its data types and operators, and Java is no exception. These elements define the limits of a language and determine the kind of tasks to which it can be applied. Fortunately, Java supports a rich assortment of both data types and operators, making it suitable for any type of programming.

Data types and operators are a large subject. We will begin here with an examination of Java’s foundational data types and its most commonly used operators. We will also take a closer look at variables and examine the expression.

Why Data Types Are Important

Data types are especially important in Java because it is a strongly typed language. This means that all operations are type checked by the compiler for type compatibility. Illegal operations will not be compiled. Thus, strong type checking helps prevent errors and enhances reliability. To enable strong type checking, all variables, expressions, and values have a type. There is no concept of a “type-less” variable, for example. Furthermore, the type of a value determines what operations are allowed on it. An operation allowed on one type might not be allowed on another.

Java’s Simple Types

Java contains two general categories of built-in data types: object-oriented and non-object-oriented. Java’s object-oriented types are defined by classes, and a discussion of classes is deferred until later. However, at the core of Java are eight simple (also called elemental or primitive) types of data, which are shown in Table 2-1. The term simple is used here to indicate that these types are not objects in an object-oriented sense, but rather, normal binary values. These simple types are not objects because of efficiency concerns. All of Java’s other data types are constructed from these simple types.

Java strictly specifies a range and behavior for each simple type, which all implementations of the Java Virtual Machine must support. Because of Java’s portability requirement, Java is uncompromising on this account. For example, an int is the same in all execution environments. This allows programs to be fully portable. There is no need to rewrite code to fit a specific platform. Although strictly specifying the size of the simple types may cause a small loss of performance in some environments, it is necessary in order to achieve portability.
Introducing Data Types and Operators

Integers

Java defines four integer types: byte, short, int, and long, which are shown here:

<table>
<thead>
<tr>
<th>Type</th>
<th>Width in Bits</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>byte</td>
<td>8</td>
<td>–128 to 127</td>
</tr>
<tr>
<td>short</td>
<td>16</td>
<td>–32,768 to 32,767</td>
</tr>
<tr>
<td>int</td>
<td>32</td>
<td>–2,147,483,648 to 2,147,483,647</td>
</tr>
<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>
</tbody>
</table>

As the table shows, all of the integer types 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.

NOTE

Technically, the Java run-time system can use any size it wants to store a simple type. However, in all cases, types must act as specified.
The most commonly used integer type is **int**. Variables of type **int** are often employed to control loops, to index arrays, and to perform general-purpose integer math.

When you need an integer that has a range greater than **int**, use **long**. For example, here is a program that computes the number of cubic inches contained in a cube that is one mile by one mile, by one mile:

```java
/*
   Compute the number of cubic inches
   in 1 cubic mile.
*/
class Inches {
    public static void main(String args[]) {
        long ci;
        long im;

        im = 5280 * 12;
        ci = im * im * im;

        System.out.println("There are " + ci + " cubic inches in cubic mile.");
    }
}
```

Here is the output from the program:

```
There are 254358061056000 cubic inches in cubic mile.
```

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

The smallest integer type is **byte**. Variables of type **byte** are especially useful when working with raw binary data that may not be directly compatible with Java’s other built-in types.

The **short** type creates a short integer that has its high-order byte first (called *big-endian* format). This type is mostly applicable to 16-bit computers, which are becoming increasingly scarce.

### Floating-Point Types

As explained in Module 1, the floating-point types can represent numbers that have fractional components. There are two kinds of floating-point types, **float** and **double**, which represent single- and double-precision numbers, respectively. The type **float** is 32 bits wide and has a
range of approximately $1.4 \times 10^{-45}$ to $3.4 \times 10^{38}$. The `double` type is 64 bits wide and has a range of approximately $4.9 \times 10^{-324}$ to $1.8 \times 10^{308}$.

Of the two, `double` is the most commonly used because all of the math functions in Java’s class library use `double` values. For example, the `sqrt()` method (which is defined by the standard `Math` class) returns a `double` value that is the square root of its `double` argument. Here, `sqrt()` is used to compute the length of the hypotenuse, given the lengths of the two opposing sides:

```java
/*
Use the Pythagorean theorem to
find the length of the hypotenuse
given the lengths of the two opposing
sides.
*/
class Hypot {
    public static void main(String args[]) {
        double x, y, z;

        x = 3;
        y = 4;

        z = Math.sqrt(x*x + y*y);

        System.out.println("Hypotenuse is "+z);
    }
}
```

The output from the program is shown here:

Hypotenuse is 5.0
One other point about the preceding example: As mentioned, \texttt{sqrt()} is a member of the standard \texttt{Math} class. Notice how \texttt{sqrt()} is called; it is preceded by the name \texttt{Math}. This is similar to the way \texttt{System.out} precedes \texttt{println()}. Although not all standard methods are called by specifying their class name first, several are.

**Characters**

In Java, characters are not 8-bit quantities like they are in most other computer languages. Instead, Java uses Unicode. \textit{Unicode} defines a character set that can represent all of the characters found in all human languages. Thus, in Java, \texttt{char} is an unsigned 16-bit type having a range of 0 to 65,536. The standard 8-bit ASCII character set is a subset of Unicode and ranges from 0 to 127. Thus, the ASCII characters are still valid Java characters.

A character variable can be assigned a value by enclosing the character in single quotes. For example, this assigns the variable \texttt{ch} the letter X:

```java
char ch;
ch = 'X';
```

You can output a \texttt{char} value using a \texttt{println()} statement. For example, this line outputs the value in \texttt{ch}:

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

Since \texttt{char} is an unsigned 16-bit type, it is possible to perform various arithmetic manipulations on a \texttt{char} variable. For example, consider the following program:

```java
// Character variables can be handled like integers.
class CharArithDemo {
    public static void main(String args[]) {
        char ch;

        ch = 'X';
        System.out.println("ch contains " + ch);

        ch++; // increment ch \texttt{A char can be incremented.}
        System.out.println("ch is now " + ch);

        ch = 90; // give ch the value Z \texttt{A char can be assigned an integer value.}
        System.out.println("ch is now " + ch);
    }
}
```
Ask the Expert

Q: Why does Java use Unicode?

A: Java was designed to allow applets to be written for worldwide use. Thus, it needs to use a character set that can represent all the world’s languages. Unicode is the standard character set designed expressly for this purpose. Of course, the use of Unicode is inefficient for languages such as English, German, Spanish, or French, whose characters can be contained within 8 bits. But such is the price that must be paid for global portability.

The output generated by this program is shown here:

ch contains X
ch is now Y
ch is now Z

In the program, ch is first given the value X. Next, ch is incremented. This results in ch containing Y, the next character in the ASCII (and Unicode) sequence. Although char is not an integer type, in some cases it can be handled as if it were. Next, ch is assigned the value 90, which is the ASCII (and Unicode) value that corresponds to the letter Z. Since the ASCII character set occupies the first 127 values in the Unicode character set, all the “old tricks” that you have used with characters in the past will work in Java, too.

The Boolean Type

The boolean type represents true/false values. Java defines the values true and false using the reserved words true and false. Thus, a variable or expression of type boolean will be one of these two values.

Here is a program that demonstrates the boolean type:

```java
// Demonstrate boolean values.
class BoolDemo {
    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 >.

Progress Check

1. What are Java’s integer types?
2. What is Unicode?
3. What values can a boolean variable have?
How Far Away Is the Lightning?

In this project you will create a program that computes how far away, in feet, a listener is from a lightning strike. Sound travels approximately 1,100 feet per second through air. Thus, knowing the interval between the time you see a lightning bolt and the time the sound reaches you enables you to compute the distance to the lightning. For this project, assume that the time interval is 7.2 seconds.

Step by Step

1. Create a new file called Sound.java.

2. To compute the distance, you will need to use floating-point values. Why? Because the time interval, 7.2, has a fractional component. Although it would be permissible to use a value of type float, we will use double in the example.

3. To compute the distance, you will multiply 7.2 by 1,100. You will then assign this value to a variable.

4. Finally, you will display the result.

Here is the entire Sound.java program listing:

```java
/*
   Project 2-1
   Compute the distance to a lightning strike whose sound takes 7.2 seconds to reach you.
*/

class Sound {
    public static void main(String args[]) {
        double dist;

        dist = 7.2 * 1100;

        System.out.println("The lightning is " + dist + " feet away.");
    }
}
```

5. Compile and run the program. The following result is displayed:

The lightning is 7920.0 feet away.

(continued)
6. Extra challenge: You can compute the distance to a large object, such as a rock wall, by timing the echo. For example, if you clap your hands and time how long it takes for you to hear the echo, then you know the total round-trip time. Dividing this value by two yields the time it takes the sound to go one way. You can then use this value to compute the distance to the object. Modify the preceding program so that it computes the distance, assuming that the time interval is that of an echo.

**Critical Skill**

### Literals

In Java, *literals* refer to fixed values that are represented in their human-readable form. For example, the number 100 is a literal. Literals are also commonly called *constants*. For the most part, literals, and their usage, are so intuitive that they have been used in one form or another by all the preceding sample programs. Now the time has come to explain them formally.

Java literals can be of any of the simple data types. The way each literal is represented depends upon its type. As explained earlier, character constants are enclosed in single quotes. For example, 'a' and ' %' are both character constants.

Integer constants are specified as numbers without fractional components. For example, 10 and –100 are integer constants. Floating-point constants require the use of the decimal point followed by the number’s fractional component. For example, 11.123 is a floating-point constant. Java also allows you to use scientific notation for floating-point numbers.

By default, integer literals are of type `int`. If you want to specify a `long` literal, append an `l` or an `L`. For example, 12 is an `int`, but 12L is a `long`.

By default, floating-point literals are of type `double`. To specify a `float` literal, append an `F` or `f` to the constant. For example, 10.19F is of type `float`.

Although integer literals create an `int` value by default, they can still be assigned to variables of type `char`, `byte`, or `short` as long as the value being assigned can be represented by the target type. An integer literal can always be assigned to a `long` variable.

### Hexadecimal and Octal Constants

As you probably know, in programming it is sometimes easier to use a number system based on 8 or 16 instead of 10. The number system based on 8 is called *octal*, and it uses the digits 0 through 7. In octal the number 10 is the same as 8 in decimal. The base 16 number system is called *hexadecimal* and uses the digits 0 through 9 plus the letters A through F, which stand for 10, 11, 12, 13, 14, and 15. For example, the hexadecimal number 10 is 16 in decimal. Because of the frequency with which these two number systems are used, Java allows you to specify integer constants in hexadecimal or octal instead of decimal. A hexadecimal constant must begin with `0x` (a zero followed by an x). An octal constant begins with a zero. Here are some examples:
hex = 0xFF; // 255 in decimal
oct = 011;  // 9 in decimal

Character Escape Sequences
Enclosing character constants in single quotes works for most printing characters, but a few
characters, such as the carriage return, pose a special problem when a text editor is used. In
addition, certain other characters, such as the single and double quotes, have special meaning
in Java, so you cannot use them directly. For these reasons, Java provides special escape sequences,
sometimes referred to as backslash character constants, shown in Table 2-2. These sequences
are used in place of the characters that they represent.

For example, this assigns ch the tab character:

ch = '\t';

The next example assigns a single quote to ch:

ch = '\'';

String Literals
Java supports one other type of literal: the string. A string is a set of characters enclosed by
double quotes. For example,

"this is a test"

<table>
<thead>
<tr>
<th>Escape Sequence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<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</td>
</tr>
<tr>
<td>\f</td>
<td>Form feed</td>
</tr>
<tr>
<td>\t</td>
<td>Horizontal tab</td>
</tr>
<tr>
<td>\b</td>
<td>Backspace</td>
</tr>
<tr>
<td>\ddd</td>
<td>Octal constant (where ddd is an octal constant)</td>
</tr>
<tr>
<td>\uxxxx</td>
<td>Hexadecimal constant (where xxxx is a hexadecimal constant)</td>
</tr>
</tbody>
</table>

Table 2-2 Character Escape Sequences
is a string. You have seen examples of strings in many of the `println()` statements in the preceding sample programs.

In addition to normal characters, a string literal can also contain one or more of the escape sequences just described. For example, consider the following program. It uses the `\n` and `\t` escape sequences.

```java
// Demonstrate escape sequences in strings.
class StrDemo {

    public static void main(String args[]) {
        System.out.println("First line\nSecond line");
        System.out.println("A\tB\tC");
        System.out.println("D\tE\tF");
    }
}
```

The output is shown here:

```
First line
Second line
A  B  C
D  E  F
```

Notice how the `\n` escape sequence is used to generate a new line. You don’t need to use multiple `println()` statements to get multiline output. Just embed `\n` within a longer string at the points where you want the new lines to occur.

**Progress Check**

1. What is the type of the literal 10? What is the type of the literal 10.0?
2. How do you specify a `long` literal?
3. Is "x" a string or a character literal?

---

1. The literal 10 is an `int`, and 10.0 is a `double`.
2. A `long` literal is specified by adding the L or l suffix. For example, 100L.
3. The literal "x" is a string.
A Closer Look at Variables

Variables were introduced in Module 1. Here, we will take a closer look at them. As you learned earlier, variables are declared using this form of statement,

type var-name;

where type is the data type of the variable, and var-name is its name. You can declare a variable of any valid type, including the simple types just described. When you create a variable, you are creating an instance of its type. Thus, the capabilities of a variable are determined by its type. For example, a variable of type boolean cannot be used to store floating-point values. Furthermore, the type of a variable cannot change during its lifetime. An int variable cannot turn into a char variable, for example.

All variables in Java must be declared prior to their use. This is necessary because the compiler must know what type of data a variable contains before it can properly compile any statement that uses the variable. It also enables Java to perform strict type checking.

Initializing a Variable

In general, you must give a variable a value prior to using it. One way to give a variable a value is through an assignment statement, as you have already seen. Another way is by giving it an initial value when it is declared. To do this, follow the variable’s name with an equal sign and the value being assigned. The general form of initialization is shown here:

\[ type\ var = value; \]
Here, *value* is the value that is given to *var* when *var* is created. The value must be compatible with the specified type. Here are some examples:

```java
int count = 10; // give count an initial value of 10
char ch = 'X';  // initialize ch with the letter X
float f = 1.2F; // f is initialized with 1.2
```

When declaring two or more variables of the same type using a comma-separated list, you can give one or more of those variables an initial value. For example:

```java
int a, b = 8, c = 19, d; // b and c have initializations
```

In this case, only *b* and *c* are initialized.

## 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 volume of a cylinder given the radius of its base and its height:

```java
// Demonstrate dynamic initialization.
class DynInit {
    public static void main(String args[]) {
        double radius = 4, height = 5; // volume is dynamically initialized at run time.

        // dynamically initialize volume
        double volume = 3.1416 * radius * radius * height;

        System.out.println("Volume is "+ volume);
    }
}
```

Here, three local variables—*radius*, *height*, and *volume*—are declared. The first two, *radius* and *height*, are initialized by constants. However, *volume* is initialized dynamically to the volume of the cylinder. The key point here is that the initialization expression can 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 that we have been using were declared at the start of the `main()` method. However, Java allows variables to be declared within any block. As explained in Module 1, 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.

Most other computer languages define two general categories of scopes: global and local. Although supported by Java, these are not the best ways to categorize Java’s scopes. The most important scopes in Java are those defined by a class and those defined by a method. A discussion of class scope (and variables declared within it) is deferred until later in this book, when classes are described. For now, we will examine only 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.

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 ScopeDemo {
    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 visible only 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.

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, that variable will be reinitialized each time the block in which it is declared is entered. For example, consider this program:

```java
// Demonstrate lifetime of a variable.
class VarInitDemo {
    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 always reinitialized to $-1$ each time the inner `for` loop is entered. Even though it is subsequently assigned the value 100, this value is lost.

There is one quirk to Java’s scope rules that may surprise you: although blocks can be nested, no variable declared within an inner scope can have the same name as a variable declared by an enclosing scope. For example, the following program, which tries to declare two separate variables with the same name, will not compile.

```java
class NestVar {
    public static void main(String args[]) {
        int count;
        for(count = 0; count < 10; count = count+1) {
            System.out.println("This is count: "+ count);
            int count; // illegal!!!
            for(count = 0; count < 2; count++)
                System.out.println("This program is in error!");
        }
    }
}
```

If you come from a C/C++ background, you know that there is no restriction on the names that you give variables declared in an inner scope. Thus, in C/C++ the declaration of `count` within the block of the outer `for` loop is completely valid, and such a declaration hides the outer variable. The designers of Java felt that this `name hiding` could easily lead to programming errors and disallowed it.
Progress Check

1. What is a scope? How can one be created?
2. Where in a block can variables be declared?
3. In a block, when is a variable created? When is it destroyed?

Operators

Java provides a rich operator environment. An operator is a symbol that tells the compiler to perform a specific mathematical or logical manipulation. Java has four general classes of operators: arithmetic, bitwise, relational, and logical. Java also defines some additional operators that handle certain special situations. This module will examine the arithmetic, relational, and logical operators. We will also examine the assignment operator. The bitwise and other special operators are examined later.

CRITICAL SKILL

2.5 Arithmetic Operators

Java defines the following arithmetic operators:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Addition</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>Decrement</td>
</tr>
</tbody>
</table>

1. A scope defines the visibility and lifetime of an object. A block defines a scope.
2. A variable can be defined at any point within a block.
3. Inside a block, a variable is created when its declaration is encountered. It is destroyed when the block exits.
The operators +, −, *, and / all work the same way in Java as they do in any other computer language (or algebra, for that matter). These can be applied to any built-in numeric data type. They can also be used on objects of type char.

Although the actions of arithmetic operators are well known to all readers, a few special situations warrant some explanation. First, remember that when / is applied to an integer, any remainder will be truncated; for example, 10/3 will equal 3 in integer division. You can obtain the remainder of this division by using the modulus operator %. It works in Java the way it does in other languages: it yields the remainder of an integer division. For example, 10 % 3 is 1. In Java, the % can be applied to both integer and floating-point types. Thus, 10.0 % 3.0 is also 1.

The following program demonstrates the modulus operator.

```java
// Demonstrate the % operator.
class ModDemo {
    public static void main(String args[]) {
        int iresult, irem;
        double dresult, drem;

        iresult = 10 / 3;
        irem = 10 % 3;

        dresult = 10.0 / 3.0;
        drem = 10.0 % 3.0;

        System.out.println("Result and remainder of 10 / 3: " +
                          iresult + " " + irem);
        System.out.println("Result and remainder of 10.0 / 3.0: " +
                          dresult + " " + drem);
    }
}
```

The output from the program is shown here:

Result and remainder of 10 / 3: 3 1
Result and remainder of 10.0 / 3.0: 3.3333333333333335 1.0

As you can see, the % yields a remainder of 1 for both integer and floating-point operations.
Increment and Decrement

Introduced in Module 1, the ++ and the -- are Java’s increment and decrement operators. 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 adds 1 to its operand, and the decrement operator subtracts 1. Therefore,

\[ x = x + 1; \]

is the same as

\[ x++; \]

and

\[ x = x - 1; \]

is the same as

\[ --x; \]

Both the increment and decrement operators can either precede (prefix) or follow (postfix) the operand. For example,

\[ x = x + 1; \]

can be written as

\[ ++x; // prefix form \]

or as

\[ x++; // postfix form \]

In the foregoing example, there is no difference whether the increment is applied as a prefix or a postfix. However, when an increment or decrement is used as part of a larger expression, there is an important difference. When an increment or decrement operator precedes its operand, Java will perform the corresponding operation prior to obtaining the operand’s value for use by the rest of the expression. If the operator follows its operand, Java will obtain the operand’s value before incrementing or decrementing it. Consider the following:

\[ x = 10; \]
\[ y = ++x; \]
In this case, \( y \) will be set to 11. However, if the code is written as

\[
\begin{align*}
x &= 10; \\
y &= x++; \\
\end{align*}
\]

then \( y \) will be set to 10. In both cases, \( x \) is still set to 11; the difference is when it happens. There are significant advantages in being able to control when the increment or decrement operation takes place.

**Critical Skill 2.6 Relational and Logical Operators**

In the terms *relational operator* and *logical operator*, *relational* refers to the relationships that values can have with one another, and *logical* refers to the ways in which true and false values can be connected together. Since the relational operators produce true or false results, they often work with the logical operators. For this reason they will be discussed together here.

The relational operators are shown here:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Meaning</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 logical operators are shown next:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;</td>
<td>AND</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>^</td>
<td>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>NOT</td>
</tr>
</tbody>
</table>

The outcome of the relational and logical operators is a *boolean* value.
In Java, all objects can be compared for equality or inequality using \( = = \) and \( != \). However, the comparison operators, \(<\), \(>\), \(<=\), or \(>=\), can be applied only to those types that support an ordering relationship. Therefore, all of the relational operators can be applied to all numeric types and to type \texttt{char}. However, values of type \texttt{boolean} can only be compared for equality or inequality, since the \texttt{true} and \texttt{false} values are not ordered. For example, \texttt{true} \(>\) \texttt{false} has no meaning in Java.

For the logical operators, the operands must be of type \texttt{boolean}, and the result of a logical operation is of type \texttt{boolean}. The logical operators, \&\&, |, ^, and !, support the basic logical operations AND, OR, XOR, and NOT, according to the following truth table.

| \(p\) | \(q\) | \(p \& q\) | \(p | q\) | \(p ^ q\) | \(!p\) |
|------|------|----------|-------|--------|-------|
| False | False | False | False | False | True  |
| True  | False | False | True  | True  | False |
| False | True  | False | True  | True  | True  |
| True  | True  | True  | True  | False | False |

As the table shows, the outcome of an exclusive OR operation is true when exactly one and only one operand is true.

Here is a program that demonstrates several of the relational and logical operators:

```java
// Demonstrate the relational and logical operators.
class RelLogOps {
    public static void main(String args[]) {
        int i, j;
        boolean b1, b2;

        i = 10;
        j = 11;
        if(i < j) System.out.println("i < j");
        if(i <= j) System.out.println("i <= j");
        if(i != j) System.out.println("i != j");
        if(i == j) System.out.println("this won't execute");
        if(i >= j) System.out.println("this won't execute");
        if(i > j) System.out.println("this won't execute");

        b1 = true;
        b2 = false;
        if(b1 && b2) System.out.println("this won't execute");
        if(!(b1 && b2)) System.out.println("!(b1 && b2) is true");
        if(b1 | b2) System.out.println("b1 | b2 is true");
        if(b1 ^ b2) System.out.println("b1 ^ b2 is true");
    }
}
```
The output from the program is shown here:

i < j
i <= j
i != j
!(b1 & b2) is true
b1 | b2 is true
b1 ^ b2 is true

Short-Circuit Logical Operators

Java supplies special short-circuit versions of its AND and OR logical operators that can be used to produce more efficient code. To understand why, consider the following. In an AND operation, if the first operand is false, the outcome is false no matter what value the second operand has. In an OR operation, if the first operand is true, the outcome of the operation is true no matter what the value of the second operand. Thus, in these two cases there is no need to evaluate the second operand. By not evaluating the second operand, time is saved and more efficient code is produced.

The short-circuit AND operator is &&, and the short-circuit OR operator is ||. Their normal counterparts are & and |. The only difference between the normal and short-circuit versions is that the normal operands will always evaluate each operand, but short-circuit versions will evaluate the second operand only when necessary.

Here is a program that demonstrates the short-circuit AND operator. The program determines whether the value in d is a factor of n. It does this by performing a modulus operation. If the remainder of n / d is zero, then d is a factor. However, since the modulus operation involves a division, the short-circuit form of the AND is used to prevent a divide-by-zero error.

// Demonstrate the short-circuit operators.
class SCops {
   public static void main(String args[]) {
      int n, d, q;
      n = 10;
      d = 2;
      if(d != 0 && (n % d) == 0)
         System.out.println(d + " is a factor of " + n);
      
      d = 0; // now, set d to zero

      // Since d is zero, the second operand is not evaluated.
      if(d != 0 && (n % d) == 0)
         System.out.println(d + " is a factor of " + n);
      
      /* Now, try same thing without short-circuit operator.

The short-circuit operator prevents a division by zero.
This will cause a divide-by-zero error.

```java
    if(d != 0 & (n % d) == 0)
        System.out.println(d + " is a factor of " + n);
```

To prevent a divide-by-zero, the if statement first checks to see if \( d \) is equal to zero. If it is, the short-circuit AND stops at that point and does not perform the modulus division. Thus, in the first test, \( d \) is 2 and the modulus operation is performed. The second test fails because \( d \) is set to zero, and the modulus operation is skipped, avoiding a divide-by-zero error. Finally, the normal AND operator is tried. This causes both operands to be evaluated, which leads to a run-time error when the division by zero occurs.

**Progress Check**

1. What does the \% operator do? To what types can it be applied?
2. What type of values can be used as operands of the logical operators?
3. Does a short-circuit operator always evaluate both of its operands?

---

**CRITICAL SKILL 2.7 The Assignment Operator**

You have been using the assignment operator since Module 1. Now it is time to take a formal look at it. The *assignment operator* is the single equal sign, =. This 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 \( expression \).

1. The \% is the modulus operator, which returns the remainder of an integer division. It can be applied to all of the numeric types.
2. The logical operators must have operands of type **boolean**.
3. No, a short-circuit operator evaluates its second operand only if the outcome of the operation cannot be determined solely by its first operand.
Ask the Expert

Q: Since the short-circuit operators are, in some cases, more efficient than their normal counterparts, why does Java still offer the normal AND and OR operators?

A: In some cases you will want both operands of an AND or OR operation to be evaluated because of the side effects produced. Consider the following:

```java
// Side effects can be important.
class SideEffects {
    public static void main(String args[]) {
        int i;
        i = 0;
        /* Here, i is still incremented even though
           the if statement fails. */
        if(false & (++i < 100))
            System.out.println("this won't be displayed");
        System.out.println("if statements executed: " + i); // displays 1
        /* In this case, i is not incremented because
           the short-circuit operator skips the increment. */
        if(false && (++i < 100))
            System.out.println("this won't be displayed");
        System.out.println("if statements executed: " + i); // still 1!!
    }
}
```

As the comments indicate, in the first `if` statement, `i` is incremented whether the `if` succeeds or not. However, when the short-circuit operator is used, the variable `i` is not incremented when the first operand is false. The lesson here is that if your code expects the right-hand operand of an AND or OR operation to be evaluated, you must use Java’s non-short-circuit forms of these operations.

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.

### Critical Skill

#### 2.8 Shorthand Assignments

Java provides special *shorthand* assignment operators that simplify the coding of certain assignment statements. Let’s begin with an example. The assignment statement shown here

\[
x = x + 10;
\]

can be written, using Java shorthand, as

\[
x += 10;
\]

The operator pair \( += \) tells the compiler to assign to \( x \) the value of \( x \) plus 10.

Here is another example. The statement

\[
x = x - 100;
\]

is the same as

\[
x -= 100;
\]

Both statements assign to \( x \) the value of \( x \) minus 100.

This shorthand will work for all the binary operators in Java (that is, those that require two operands). The general form of the shorthand is

\[
var op = expression;
\]

Thus, the arithmetic and logical assignment operators are the following:

\[
\begin{array}{c}
+= \\
-= \\
%= \\
&=
\end{array} \quad \begin{array}{c}
*=
\\ /=
\end{array}
\]

The assignment operators provide two benefits. First, they are more compact than their “longhand” equivalents. Second, they are implemented more efficiently by the Java run-time system. For these reasons, you will often see the assignment operators used in professionally written Java programs.
Type Conversion in Assignments

In programming, it is common to assign one type of variable to another. For example, you might want to assign an `int` value to a `float` variable, as shown here:

```java
int i;
float f;

i = 10;
f = i; // assign an int to a float
```

When compatible types are mixed in an assignment, the value of the right side is automatically converted to the type of the left side. Thus, in the preceding fragment, the value in `i` is converted into a `float` and then assigned to `f`. However, because of Java’s strict type checking, not all types are compatible, and thus, not all type conversions are implicitly allowed. For example, `boolean` and `int` are not compatible.

When one type of data is assigned to another type of variable, an automatic type conversion will take place if

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

When these two conditions are met, a widening conversion takes place. For example, the `int` type is always large enough to hold all valid `byte` values, and both `int` and `byte` are integer types, so an automatic conversion from `byte` to `int` can be applied.

For widening conversions, the numeric types, including integer and floating-point types, are compatible with each other. For example, the following program is perfectly valid since `long` to `double` is a widening conversion that is automatically performed.

```java
// Demonstrate automatic conversion from long to double.
class LtoD {
    public static void main(String args[]) {
        long L;
        double D;

        L = 100123285L;
        D = L; // Automatic conversion from long to double

        System.out.println("L and D: "+ L + " " + D);
    }
}
```
Although there is an automatic conversion from `long` to `double`, there is no automatic conversion from `double` to `long` since this is not a widening conversion. Thus, the following version of the preceding program is invalid.

```java
// *** This program will not compile. ***
class LtoD {
    public static void main(String args[]) {
        long L;
        double D;

        D = 100123285.0;
        L = D; // Illegal!!!
        System.out.println("L and D: " + L + " + D");
    }
}
```

There are no automatic conversions from the numeric types to `char` or `boolean`. Also, `char` and `boolean` are not compatible with each other. However, an integer literal can be assigned to `char`.

### CRITICAL SKILL

**2.10 Casting Incompatible Types**

Although the automatic type conversions are helpful, they will not fulfill all programming needs because they apply only to widening conversions between compatible types. For all other cases you must employ a cast. A cast is an instruction to the compiler to convert one type into another. Thus, it requests an explicit type conversion. A cast has this general form:

```
(target-type) expression
```

Here, `target-type` specifies the desired type to convert the specified expression to. For example, if you want to convert the type of the expression `x/y` to `int`, you can write

```java
double x, y;
// ...
(int) (x / y)
```

Here, even though `x` and `y` are of type `double`, the cast converts the outcome of the expression to `int`. The parentheses surrounding `x / y` are necessary. Otherwise, the cast to `int` would apply only to the `x` and not to the outcome of the division. The cast is necessary here because there is no automatic conversion from `double` to `int`.

When a cast involves a narrowing conversion, information might be lost. For example, when casting a `long` into a `short`, information will be lost if the `long`'s value is greater than
the range of a **short** because its high-order bits are removed. When a floating-point value is cast to an integer type, the fractional component will also be lost due to truncation. For example, if the value 1.23 is assigned to an integer, the resulting value will simply be 1. The 0.23 is lost.

The following program demonstrates some type conversions that require casts:

```java
// Demonstrate casting.
class CastDemo {
    public static void main(String args[]) {
        double x, y;
        byte b;
        int i;
        char ch;

        x = 10.0;
        y = 3.0;
        i = (int) (x / y); // cast double to int
        System.out.println("Integer outcome of x / y: " + i);

        i = 100;
        b = (byte) i; // cast int to byte
        System.out.println("Value of b: " + b);

        i = 257;
        b = (byte) i; // cast int to byte
        System.out.println("Value of b: " + b);

        b = 88; // ASCII code for X
        ch = (char) b; // cast byte to char
        System.out.println("ch: " + ch);
    }
}
```

The output from the program is shown here:

```
Integer outcome of x / y: 3
Value of b: 100
Value of b: 1
ch: X
```

In the program, the cast of $(x / y)$ to **int** results in the truncation of the fractional component, and information is lost. Next, no loss of information occurs when **b** is assigned the value 100 because a **byte** can hold the value 100. However, when the attempt is made to assign **b** the value 257, information loss occurs because 257 exceeds a **byte**’s maximum value. Finally, no information is lost, but a cast is needed when assigning a **byte** value to a **char**.
Progress Check

1. What is a cast?

2. Can a short be assigned to an int without a cast? Can a byte be assigned to a char without a cast?

3. How can the following statement be rewritten?
   \[ x = x + 23; \]

Operator Precedence

The following table shows the order of precedence for all Java operators, from highest to lowest. This table includes several operators that will be discussed later in this book.

<table>
<thead>
<tr>
<th>highest</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(</td>
<td>]</td>
<td>.</td>
<td></td>
</tr>
<tr>
<td>++</td>
<td>--</td>
<td>~</td>
<td>!</td>
</tr>
<tr>
<td>*</td>
<td>/</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;&gt;</td>
<td>&gt;&gt;&gt;</td>
<td></td>
<td>&lt;=</td>
</tr>
<tr>
<td>&gt;</td>
<td>&gt;=</td>
<td>&lt;</td>
<td></td>
</tr>
<tr>
<td>==</td>
<td>!=</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&amp;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>^</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&amp;&amp;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>? :</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>=</td>
<td></td>
<td>op=</td>
<td></td>
</tr>
</tbody>
</table>

lowest

1. A cast is an explicit conversion.
2. Yes. No.
3. x += 23;
Project 2-2: Display a Truth Table for the Logical Operators

In this project you will create a program that displays the truth table for Java’s logical operators. You must make the columns in the table line up. This project makes use of several features covered in this module, including one of Java’s escape sequences and the logical operators. It also illustrates the differences in the precedence between the arithmetic + operator and the logical operators.

Step by Step

1. Create a new file called LogicalOpTable.java.

2. To ensure that the columns line up, you will use the \t escape sequence to embed tabs into each output string. For example, this println( ) statement displays the header for the table:

   ```java
   System.out.println("P\tQ\tAND\tOR\tXOR\tNOT");
   ```

3. Each subsequent line in the table will use tabs to position the outcome of each operation under its proper heading.

4. Here is the entire LogicalOpTable.java program listing. Enter it at this time.

   ```java
   // Project 2-2: a truth table for the logical operators.
   class LogicalOpTable {
       public static void main(String args[]) {

           boolean p, q;
           System.out.println("P\tQ\tAND\tOR\tXOR\tNOT");

           p = true; q = true;
           System.out.print(p + "\t" + q +"\t");
           System.out.print((p&q) + "\t" + (p|q) + "\t");
           System.out.println((p^q) + "\t" + (!p));

           p = true; q = false;
           System.out.print(p + "\t" + q +"\t");
           System.out.print((p&q) + "\t" + (p|q) + "\t");
           System.out.println((p^q) + "\t" + (!p));

           p = false; q = true;
           System.out.print(p + "\t" + q +"\t");
           System.out.print((p&q) + "\t" + (p|q) + "\t");
           System.out.println((p^q) + "\t" + (!p));
   }
   ```

(continued)
p = false; q = false;
System.out.print(p + "\t" + q +"\t");
System.out.println((p&q) + "\t" + (p|q) + "\t");
System.out.println((p^q) + "\t" + (!p));
}
}

Notice the parentheses surrounding the logical operations inside the println() statements. They are necessary because of the precedence of Java’s operators. The + operator is higher than the logical operators.

5. Compile and run the program. The following table is displayed.

<table>
<thead>
<tr>
<th>P</th>
<th>Q</th>
<th>AND</th>
<th>OR</th>
<th>XOR</th>
<th>NOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>true</td>
<td>true</td>
<td>true</td>
<td>true</td>
<td>false</td>
<td>false</td>
</tr>
<tr>
<td>true</td>
<td>false</td>
<td>false</td>
<td>true</td>
<td>true</td>
<td>false</td>
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<td>false</td>
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</tr>
<tr>
<td>false</td>
<td>false</td>
<td>false</td>
<td>false</td>
<td>false</td>
<td>true</td>
</tr>
</tbody>
</table>

6. On your own, try modifying the program so that it uses and displays 1’s and 0’s, rather than true and false. This may involve a bit more effort than you might at first think!

CRITICAL SKILL

2.11 Expressions

Operators, variables, and literals are the constituents of expressions. An expression in Java is any valid combination of those pieces. You probably already know the general form of an expression from your other programming experience, or from algebra. However, a few aspects of expressions will be discussed now.

Type Conversion in Expressions

Within an expression, it is possible to mix two or more different types of data as long as they are compatible with each other. For example, you can mix short and long within an expression because they are both numeric types. When different types of data are mixed within an expression, they are all converted to the same type. This is accomplished through the use of Java’s type promotion rules.

First, all char, byte, and short values are promoted to int. Then, if one operand is a long, the whole expression is promoted to long. If one operand is a float operand, the entire expression is promoted to float. If any of the operands is double, the result is double.

It is important to understand that type promotions apply only to the values operated upon when an expression is evaluated. For example, if the value of a byte variable is promoted to int inside an expression, outside the expression, the variable is still a byte. Type promotion only affects the evaluation of an expression.
Type promotion can, however, lead to somewhat unexpected results. For example, when an arithmetic operation involves two `byte` values, the following sequence occurs: First, the `byte` operands are promoted to `int`. Then the operation takes place, yielding an `int` result. Thus, the outcome of an operation involving two `byte` values will be an `int`. This is not what you might intuitively expect. Consider the following program:

```java
// A promotion surprise!
class PromDemo {
    public static void main(String args[]) {
        byte b;
        int i;
        b = 10;   // No cast needed because result is already elevated to int.
        i = b * b; // OK, no cast needed
        b = 10;
        b = (byte) (b * b); // cast needed!!
        System.out.println("i and b: " + i + " " + b);
    }
}
```

Somewhat counterintuitively, no cast is needed when assigning `b * b` to `i`, because `b` is promoted to `int` when the expression is evaluated. However, when you try to assign `b * b` to `b`, you do need a cast—back to `byte`! Keep this in mind if you get unexpected type-incompatibility error messages on expressions that would otherwise seem perfectly OK.

This same sort of situation also occurs when performing operations on `char`s. For example, in the following fragment, the cast back to `char` is needed because of the promotion of `ch1` and `ch2` to `int` within the expression.

```java
char ch1 = 'a', ch2 = 'b';

ch1 = (char) (ch1 + ch2);
```

Without the cast, the result of adding `ch1` to `ch2` would be `int`, which can’t be assigned to a `char`.

Casts are not only useful when converting between types in an assignment. For example, consider the following program. It uses a cast to `double` to obtain a fractional component from an otherwise integer division.

```java
// Using a cast.
class UseCast {
    public static void main(String args[]) {
        int i;
```
for(i = 0; i < 5; i++) {
    System.out.println(i + " / 3: " + i / 3);
    System.out.println(i + " / 3 with fractions: "
        + (double) i / 3);
    System.out.println();
}

The output from the program is shown here:

0 / 3: 0
0 / 3 with fractions: 0.0

1 / 3: 0
1 / 3 with fractions: 0.3333333333333333

2 / 3: 0
2 / 3 with fractions: 0.6666666666666666

3 / 3: 1
3 / 3 with fractions: 1.0

4 / 3: 1
4 / 3 with fractions: 1.3333333333333333

Spacing and Parentheses

An expression in Java may have tabs and spaces in it to make it more readable. For example, the following two expressions are the same, but the second is easier to read:

\[
x = \frac{10}{y} \times \left( \frac{127}{x} \right);
\]

\[
x = 10 \div y \times \left( \frac{127}{x} \right);
\]

Parentheses increase the precedence of the operations contained within them, just like in algebra. Use of redundant or additional parentheses will not cause errors or slow down the execution of the expression. You are encouraged to use parentheses to make clear the exact order of evaluation, both for yourself and for others who may have to figure out your program later. For example, which of the following two expressions is easier to read?

\[
x = \frac{y}{3} - 34 \times \text{temp} + 127;
\]

\[
x = \left( \frac{y}{3} \right) - (34 \times \text{temp}) + 127;
\]
Module 2 Mastery Check

1. Why does Java strictly specify the range and behavior of its simple types?

2. What is Java’s character type, and how does it differ from the character type used by many other programming languages?

3. A boolean value can have any value you like because any non-zero value is true. True or False?

4. Given this output,
   
   One
   Two
   Three

   using a single string, show the println() statement that produced it.

5. What is wrong with this fragment?
   
   ```java
   for(i = 0; i < 10; i++) {
       int sum;
       
       sum = sum + i;
   }
   System.out.println("Sum is: " + sum);
   
   ```

6. Explain the difference between the prefix and postfix forms of the increment operator.

7. Show how a short-circuit AND can be used to prevent a divide-by-zero error.

8. In an expression, what type are byte and short promoted to?

9. In general, when is a cast needed?

10. Write a program that finds all of the prime numbers between 1 and 100.

11. Does the use of redundant parentheses affect program performance?

12. Does a block define a scope?
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Module 3

Program Control Statements

CRITICAL SKILLS

3.1 Input characters from the keyboard
3.2 Know the complete form of the if statement
3.3 Use the switch statement
3.4 Know the complete form of the for loop
3.5 Use the while loop
3.6 Use the do-while loop
3.7 Use break to exit a loop
3.8 Use break as a form of goto
3.9 Apply continue
3.10 Nest loops
In this module you will learn about the statements that control a program’s flow of execution. There are three categories of program control statements: selection statements, which include the if and the switch; iteration statements, which include the for, while, and do-while loops; and jump statements, which include break, continue, and return. Except for return, which is discussed later in this book, the remaining control statements, including the if and for statements to which you have already had a brief introduction, are examined in detail here. The module begins by explaining how to perform some simple keyboard input.

**Input Characters from the Keyboard**

Before examining Java’s control statements, we will make a short digression that will allow you to begin writing interactive programs. Up to this point, the sample programs in this book have displayed information to the user, but they have not received information from the user. Thus, you have been using console output, but not console (keyboard) input. The main reason for this is that Java’s input system relies upon a rather complex system of classes, the use of which requires an understanding of various features, such as exception handling and classes, that are not discussed until later in this book. There is no direct parallel to the very convenient println( ) method, for example, that allows you to read various types of data entered by the user. Frankly, Java’s approach to console input is not as easy to use as one might like. Also, most real-world Java programs and applets will be graphical and window based, not console based. For these reasons, not much use of console input is found in this book. However, there is one type of console input that is easy to use: reading a character from the keyboard. Since several of the examples in this module will make use of this feature, it is discussed here.

The easiest way to read a character from the keyboard is to call System.in.read( ).

System.in is the complement to System.out. It is the input object attached to the keyboard. The read( ) method waits until the user presses a key and then returns the result. The character is returned as an integer, so it must be cast into a char to assign it to a char variable. By default, console input is line buffered, so you must press ENTER before any character that you type will be sent to your program. Here is a program that reads a character from the keyboard:

```java
// Read a character from the keyboard.
class KbIn {
    public static void main(String args[])
        throws java.io.IOException {
```

Program Control Statements

```java
char ch;

System.out.print("Press a key followed by ENTER: ");

ch = (char) System.in.read(); // get a char

System.out.println("Your key is: " + ch);
}
```

Here is a sample run:

Press a key followed by ENTER: t
Your key is: t

In the program, notice that `main()` begins like this:

```java
public static void main(String args[])
    throws java.io.IOException {
```

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 mechanism, which is discussed in Module 9. For now, don’t worry about its precise meaning.

The fact that `System.in` is line buffered is a source of annoyance at times. When you press ENTER, a carriage return, line feed sequence is entered into the input stream. Furthermore, these characters are left pending in the input buffer until you read them. Thus, for some applications, you may need to remove them (by reading them) before the next input operation. You will see an example of this later in this module.

**Progress Check**

1. What is `System.in`?
2. How can you read a character typed at the keyboard?

---

1. `System.in` is the input object linked to standard input, which is usually the keyboard.
2. To read a character, call `System.in.read()`.
3.2 The if Statement

Module 1 introduced the if statement. It is examined in detail here. The complete form of the if statement is

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

where the targets of the if and else are single statements. The else clause is optional. The targets of both the if and else can be blocks of statements. The general form of the if, using blocks of statements, is

```java
if(condition)
{
    statement sequence
}
else
{
    statement sequence
}
```

If the conditional expression is true, the target of the if will be executed; otherwise, if it exists, the target of the else will be executed. At no time will both of them be executed. The conditional expression controlling the if must produce a boolean result.

To demonstrate the if (and several other control statements), we will create and develop a simple computerized guessing game that would be suitable for small children. In the first version of the game, the program asks the player for a letter between A and Z. If the player presses the correct letter on the keyboard, the program responds by printing the message **Right**. The program is shown here:

```java
// Guess the letter game.
class Guess {
    public static void main(String args[])
        throws java.io.IOException {

        char ch, answer = 'K';

        System.out.println("I'm thinking of a letter between A and Z.");
        System.out.print("Can you guess it: ");

        ch = (char) System.in.read(); // read a char from the keyboard

        if(ch == answer) System.out.println("** Right **");
    }
}
```
This program prompts the player and then reads a character from the keyboard. Using an if statement, it then checks that character against the answer, which is K in this case. If K was entered, the message is displayed. When you try this program, remember that the K must be entered in uppercase.

Taking the guessing game further, the next version uses the else to print a message when the wrong letter is picked.

```java
// Guess the letter game, 2nd version.
class Guess2 {
    public static void main(String args[]) throws java.io.IOException {
        char ch, answer = 'K';

        System.out.println("I'm thinking of a letter between A and Z.");
        System.out.print("Can you guess it: ");

        ch = (char) System.in.read(); // get a char

        if(ch == answer) System.out.println("** Right **");
        else System.out.println("...Sorry, you're wrong.");
    }
}
```

### 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. The main thing to remember about nested ifs in Java is that an else statement always refers to the nearest if statement that is within the same block as the else and not already associated with an else. Here is an example:

```java
if(i == 10) {
    if(j < 20) a = b;
    if(k > 100) c = d;
    else a = c; // this else refers to if(k > 100)
} 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.
You can use a nested if to add a further improvement to the guessing game. This addition provides the player with feedback about a wrong guess.

```java
// Guess the letter game, 3rd version.
class Guess3 {
    public static void main(String args[]) throws java.io.IOException {
        char ch, answer = 'K';

        System.out.println("I'm thinking of a letter between A and Z.");
        System.out.print("Can you guess it: ");

        ch = (char) System.in.read(); // get a char

        if(ch == answer) System.out.println("** Right **");
        else {
            System.out.print("...Sorry, you're ");

            // a nested if
            if(ch < answer) System.out.println("too low");
            else System.out.println("too high");
        }
    }
}
```

A sample run is shown here:

I'm thinking of a letter between A and Z.
Can you guess it: Z
...Sorry, you're too high

The if-else-if Ladder

A common programming construct that is based upon the nested if is the **if-else-if ladder**. It looks like this:

```java
if(condition)
    statement;
else if(condition)
    statement;
else if(condition)
    statement;
```
Program Control Statements

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

The following program demonstrates the if-else-if ladder:

```java
// Demonstrate an if-else-if ladder.
class Ladder {
    public static void main(String args[]) {
        int x;

        for(x=0; x<6; x++) {
            if(x==1)
                System.out.println("x is one");
            else if(x==2)
                System.out.println("x is two");
            else if(x==3)
                System.out.println("x is three");
            else if(x==4)
                System.out.println("x is four");
            else
                System.out.println("x is not between 1 and 4");
        }
    }
}
```

The program produces the following output:

```
x is not between 1 and 4
x is one
x is two
x is three
x is four
x is not between 1 and 4
```

As you can see, the default else is executed only if none of the preceding if statements succeeds.
Progress Check

1. The condition controlling the if must be of what type?
2. To what if does an else always associate?
3. What is an if-else-if ladder?

The switch Statement

The second of Java’s selection statements is the switch. The switch provides for a multiway branch. Thus, it enables a program to select among several alternatives. Although a series of nested if statements can perform multiway tests, for many situations the switch is a more efficient approach. It works like this: the value of an expression is successively tested against a list of constants. When a match is found, the statement sequence associated with that match is executed. The general form of the switch statement is

```java
switch(expression) {
    case constant1:
        statement sequence
        break;
    case constant2:
        statement sequence
        break;
    case constant3:
        statement sequence
        break;
    .
    .
    .
    default:
        statement sequence
}
```

1. The condition controlling an if must be of type boolean.
2. An else always associates with the nearest if in the same block that is not already associated with an else.
3. An if-else-if ladder is a sequence of nested if-else statements.
The `switch` expression must be of type `char`, `byte`, `short`, or `int`. (Floating-point expressions, for example, are not allowed.) Frequently, the expression controlling the `switch` is simply a variable. The `case` constants must be literals of a type compatible with the expression. No two `case` constants in the same `switch` can have identical values.

The `default` statement sequence is executed if no `case` constant matches the expression. The `default` is optional; if it is not present, no action takes place if all matches fail. When a match is found, the statements associated with that `case` are executed until the `break` is encountered or, in the case of `default` or the last `case`, until the end of the `switch` is reached.

The following program demonstrates the `switch`.

```java
// Demonstrate the switch.
class SwitchDemo {
    public static void main(String args[]) {
        int i;

        for(i=0; i<10; i++)
            switch(i) {
                case 0:
                    System.out.println("i is zero");
                    break;
                case 1:
                    System.out.println("i is one");
                    break;
                case 2:
                    System.out.println("i is two");
                    break;
                case 3:
                    System.out.println("i is three");
                    break;
                case 4:
                    System.out.println("i is four");
                    break;
                default:
                    System.out.println("i is five or more");
            }
    }
}
```
The output produced by this program is shown here:

i is zero
i is one
i is two
i is three
i is four
i is five or more
i is five or more
i is five or more
i is five or more
i is five or more

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. When i is five or greater, no case statements match, so the default statement is executed.

Technically, the break statement is optional, although most applications of the switch will use it. When encountered within the statement sequence of a case, the break statement causes program flow to exit from the entire switch statement and resume at the next statement outside the switch. However, if a break statement does not end the statement sequence associated with a case, then all the statements at and following the matching case will be executed until a break (or the end of the switch) is encountered.

For example, study the following program carefully. Before looking at the output, can you figure out what it will display on the screen?

// Demonstrate the switch without break statements.
class NoBreak {
    public static void main(String args[]) {
        int i;

        for(i=0; i<5; i++) {
            switch(i) {
                case 0:
                    System.out.println("i is less than one");
                case 1:
                    System.out.println("i is less than two");
                case 2:
                    System.out.println("i is less than three");
                case 3:
                    System.out.println("i is less than four");
                case 4:
                    System.out.println("i is less than five");
    The case statements fall through here.
This program displays the following output:

```
System.out.println();
```

```
i is less than one
i is less than two
i is less than three
i is less than four
i is less than five

i is less than two
i is less than three
i is less than four
i is less than five

i is less than three
i is less than four
i is less than five

i is less than four
i is less than five

i is less than five
```

As this program illustrates, execution will continue into the next case if no break statement is present.

You can have empty cases, as shown in this example:

```
switch(i) {
    case 1:
    case 2:
    case 3: System.out.println("i is 1, 2 or 3");
        break;
    case 4: System.out.println("i is 4");
        break;
}
```

In this fragment, if i has the value 1, 2, or 3, the first println() statement executes. If it is 4, the second println() statement executes. The “stacking” of cases, as shown in this example, is common when several cases share common code.
Nested switch Statements

It is possible to have a switch as part of the statement sequence of an outer switch. This is called a nested switch. Even if the case constants of the inner and outer switch contain common values, no conflicts will arise. For example, the following code fragment is perfectly acceptable.

```
switch(ch1) {
    case 'A': System.out.println("This A is part of outer switch.");
    switch(ch2) {
        case 'A':
            System.out.println("This A is part of inner switch");
            break;
        case 'B': // ...
    } // end of inner switch
    break;
    case 'B': // ...
```

Progress Check

1. The expression controlling the switch must be of what type?
2. When the switch expression matches a case constant, what happens?
3. If a case sequence does not end in break, what happens?

1. The switch expression must evaluate to char, short, int, or byte.
2. When a matching case constant is found, the statement sequence associated with that case is executed.
3. If a case sequence does not end with break, execution continues into the next case sequence, if one exists.
Project 3-1  Start Building a Java Help System

This project builds a simple help system that displays the syntax for the Java control statements. The program displays a menu containing the control statements and then waits for you to choose one. After one is chosen, the syntax of the statement is displayed. In this first version of the program, help is available for only the if and switch statements. The other control statements are added in subsequent projects.

Step by Step

1. Create a file called Help.java.

2. The program begins by displaying the following menu:

   Help on:
   1. if
   2. switch
   Choose one:

   To accomplish this, you will use the statement sequence shown here:

   ```java
   System.out.println("Help on:");
   System.out.println("  1. if");
   System.out.println("  2. switch");
   System.out.print("Choose one: ");
   ```

3. Next, the program obtains the user’s selection by calling `System.in.read()`, as shown here:

   ```java
   choice = (char) System.in.read();
   ```

4. Once the selection has been obtained, the program uses the switch statement shown here to display the syntax for the selected statement.

   ```java
   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("} ");
   ```

(continued)
break;
default:
    System.out.print("Selection not found.");
}

Notice how the default clause catches invalid choices. For example, if the user enters 3, no case constants will match, causing the default sequence to execute.

5. Here is the entire Help.java program listing:

/*
   Project 3-1

   A simple help system.
*/
class Help {
    public static void main(String args[])
        throws java.io.IOException {
        char choice;

        System.out.println("Help on:");
        System.out.println("  1. if");
        System.out.println("  2. switch");
        System.out.print("Choose one: ");
        choice = (char) System.in.read();

        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;
default:
    System.out.print("Selection not found.");
}
}
}

6. Here is a sample run.

Help on:
  1. if
  2. switch
Choose one: 1

The if:

if(condition) statement;
else statement;

---

Ask the Expert

**Q:** Under what conditions should I use an if-else-if ladder rather than a switch when coding a multiway branch?

**A:** In general, use an if-else-if ladder when the conditions controlling the selection process do not rely upon a single value. For example, consider the following if-else-if sequence:

```java
if(x < 10) // ...
else if(y != 0) // ...
else if(!done) // ...
```

This sequence cannot be recoded into a switch because all three conditions involve different variables—and differing types. What variable would control the switch? Also, you will need to use an if-else-if ladder when testing floating-point values or other objects that are not of types valid for use in a switch expression.
You have been using a simple form of the for loop since Module 1. You might be surprised at just how powerful and flexible the for loop is. Let’s begin by reviewing the basics, starting with the most traditional forms of the for.

The general form of the for loop for repeating a single statement is

\[
\text{for(\text{initialization}; \text{condition}; \text{iteration}) \text{ statement;}}
\]

For repeating a block, the general form is

\[
\text{for(\text{initialization}; \text{condition}; \text{iteration})}
\]
\[
\{ \text{statement sequence} \}
\]

The initialization is usually an assignment statement that sets the initial value of the loop control variable, which acts as the counter that controls the loop. The condition is a Boolean expression that determines whether or not the loop will repeat. The iteration expression defines the amount by which the loop control variable will change each time the loop is repeated. Notice that these three major sections of the loop must be separated by semicolons. The for loop will continue to execute as long as the condition tests true. Once the condition becomes false, the loop will exit, and program execution will resume on the statement following the for.

The following program uses a for loop to print the square roots of the numbers between 1 and 99. It also displays the rounding error present for each square root.

```java
// Show square roots of 1 to 99 and the rounding error.
class SqrRoot {
    public static void main(String args[]) {
        double num, sroot, rerr;

        for(num = 1.0; num < 100.0; num++) {
            sroot = Math.sqrt(num);
            System.out.println("Square root of "+num+
                                    " is "+sroot);

            // compute rounding error
            rerr = num - (sroot * sroot);
            System.out.println("Rounding error is "+rerr);
        }
    }
}
```
Notice that the rounding error is computed by squaring the square root of each number. This result is then subtracted from the original number, thus yielding the rounding error.

The for loop can proceed in a positive or negative fashion, and it can change the loop control variable by any amount. For example, the following program prints the numbers 100 to –95, in decrements of 5.

```java
// A negatively running for loop.
class DecrFor {
    public static void main(String args[]) {
        int x;

        for(x = 100; x > -100; x -= 5) // Loop control variable is decremented by 5 each time.
            System.out.println(x);
    }
}
```

An important point about for loops is that the conditional expression is always tested at the top of the loop. This means that the code inside the loop may not be executed at all if the condition is false to begin with. Here is an example:

```java
for(count=10; count < 5; count++)
    x += count; // this statement will not execute
```

This loop will never execute because its control variable, count, is greater than 5 when the loop is first entered. This makes the conditional expression, count < 5, false from the outset; thus, not even one iteration of the loop will occur.

**Some Variations on the for Loop**

The for is one of the most versatile statements in the Java language because it allows a wide range of variations. For example, multiple loop control variables can be used. Consider the following program:

```java
// Use commas in a for statement.
class Comma {
    public static void main(String args[]) {
        int i, j;

        for(i=0, j=10; i < j; i++, j--) // Notice the two loop control variables.
            System.out.println("i and j: " + i + " " + j);
    }
}
```
The output from the program is shown here:

```
i and j: 0 10
i and j: 1 9
i and j: 2 8
i and j: 3 7
i and j: 4 6
```

Here, commas separate the two initialization statements and the two iteration expressions. When the loop begins, both i and j are initialized. Each time the loop repeats, i is incremented and j is decremented. Multiple loop control variables are often convenient and can simplify certain algorithms. You can have any number of initialization and iteration statements, but in practice, more than two or three make the for loop unwieldy.

The condition controlling the loop can be any valid Boolean expression. It does not need to involve the loop control variable. In the next example, the loop continues to execute until the user types the letter S at the keyboard.

```
// Loop until an S is typed.
class ForTest {
    public static void main(String args[])
        throws java.io.IOException {

        int i;

        System.out.println("Press S to stop.");

        for(i = 0; (char) System.in.read() != 'S'; i++)
            System.out.println("Pass #" + i);
    }
}
```

### Missing Pieces

Some interesting for loop variations are created by leaving pieces of the loop definition empty. In Java, it is possible for any or all of the initialization, condition, or iteration portions of the for loop to be blank. For example, consider the following program.

```
// Parts of the for can be empty.
class Empty {
    public static void main(String args[]) {
        int i;

        for(i = 0; i < 10; ) {
            System.out.println("Pass #" + i);
            // The iteration expression is missing.
        }
    }
}
```
Here, the iteration expression of the for is empty. Instead, the loop control variable i is incremented inside the body of the loop. This means that each time the loop repeats, i is tested to see whether it equals 10, but no further action takes place. Of course, since i is still incremented within the body of the loop, the loop runs normally, displaying the following output:

Pass #0
Pass #1
Pass #2
Pass #3
Pass #4
Pass #5
Pass #6
Pass #7
Pass #8
Pass #9

In the next example, the initialization portion is also moved out of the for.

// Move more out of the for loop.
class Empty2 {
    public static void main(String args[]) {
        int i;
        i = 0; // move initialization out of loop
        for(; i < 10; ) {
            System.out.println("Pass #" + i);
            i++; // increment loop control var
        }
    }
}

In this version, i is initialized before the loop begins, rather than as part of the for. Normally, you will want to initialize the loop control variable inside the for. Placing the initialization outside of the loop is generally done only when the initial value is derived through a complex process that does not lend itself to containment inside the for statement.
The Infinite Loop

You can create an infinite loop (a loop that never terminates) using the for by leaving the conditional expression empty. For example, the following fragment shows the way most Java programmers create an infinite loop.

```java
for(;;) // intentionally infinite loop
{
    //...
}
```

This loop will run forever. Although there are some programming tasks, such as operating system command processors, that require an infinite loop, most “infinite loops” are really just loops with special termination requirements. Near the end of this module you will see how to halt a loop of this type. (Hint: it’s done using the break statement.)

Loops with No Body

In Java, the body associated with a for loop (or any other loop) can be empty. This is because a null statement is syntactically valid. Body-less loops are often useful. For example, the following program uses one to sum the numbers 1 through 5.

```java
// The body of a loop can be empty.
class Empty3 {
    public static void main(String args[]) {
        int i;
        int sum = 0;

        // sum the numbers through 5
        for(i = 1; i <= 5; sum += i++) ;  // No body in this loop!

        System.out.println("Sum is " + sum);
    }
}
```

The output from the program is shown here:

```
Sum is 15
```

Notice that the summation process is handled entirely within the for statement, and no body is needed. Pay special attention to the iteration expression:

```
sum += i++
```
Don’t be intimidated by statements like this. They are common in professionally written Java programs and are easy to understand if you break them down into their parts. In words, this statement says “add to sum the value of sum plus i, then increment i.” Thus, it is the same as this sequence of statements:

\[
\text{sum} = \text{sum} + \text{i}; \\
i++; \\
\]

### 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, the following program computes both the summation and the factorial of the numbers 1 through 5. It declares its loop control variable i inside the for.

```java
// Declare loop control variable inside the for.
class ForVar {
    public static void main(String args[]) {
        int sum = 0;
        int fact = 1;

        // compute the factorial of the numbers through 5
        for(int i = 1; i <= 5; i++) {
            sum += i;  // i is known throughout the loop
            fact *= i;
        }

        // but, i is not known here.
        System.out.println("Sum is "+ sum);
        System.out.println("Factorial is "+ fact);
    }
}
```

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. Thus, in the preceding example, i is not accessible outside the for loop. 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.

Before moving on, you might want to experiment with your own variations on the for loop. As you will find, it is a fascinating loop.
Progress Check

1. Can portions of a for statement be empty?
2. Show how to create an infinite loop using for.
3. What is the scope of a variable declared within a for statement?

3.5 The while Loop

Another of Java’s loops is the while. The general form of the while loop is

```
while(condition) statement;
```

where statement may be a single statement or a block of statements, and condition defines the condition that controls the loop, and it may be any valid Boolean expression. The loop repeats while the condition is true. When the condition becomes false, program control passes to the line immediately following the loop.

Here is a simple example in which a while is used to print the alphabet:

```java
// Demonstrate the while loop.
class WhileDemo {
    public static void main(String args[]) {
        char ch;

        // print the alphabet using a while loop
        ch = 'a';
        while(ch <= 'z') {
            System.out.print(ch);
            ch++;
        }
    }
}
```

Here, ch is initialized to the letter a. Each time through the loop, ch is output and then incremented. This process continues until ch is greater than z.

1. Yes. All three parts of the for—initialization, condition, and iteration—can be empty.
2. for(;;)
3. The scope of a variable declared within a for is limited to the loop. Outside the loop, it is unknown.
As with the \texttt{for} loop, the \texttt{while} checks the conditional expression at the top of the loop, which means that the loop code may not execute at all. This eliminates the need for performing a separate test before the loop. The following program illustrates this characteristic of the \texttt{while} loop. It computes the integer powers of 2, from 0 to 9.

```java
// Compute integer powers of 2.
class Power {
    public static void main(String args[]) {
        int e;
        int result;

        for(int i=0; i < 10; i++) {
            result = 1;
            e = i;
            while(e > 0) {
                result *= 2;
                e--;
            }

            System.out.println("2 to the "+i+
                     " power is "+result);
        }
    }
}
```

The output from the program is shown here:

2 to the 0 power is 1
2 to the 1 power is 2
2 to the 2 power is 4
2 to the 3 power is 8
2 to the 4 power is 16
2 to the 5 power is 32
2 to the 6 power is 64
2 to the 7 power is 128
2 to the 8 power is 256
2 to the 9 power is 512

Notice that the \texttt{while} loop executes only when \texttt{e} is greater than 0. Thus, when \texttt{e} is zero, as it is in the first iteration of the \texttt{for} loop, the \texttt{while} loop is skipped.
CRITICAL SKILL 3.6 The do-while Loop

The last of Java’s loops is the do-while. Unlike the for and the while loops, in which the condition is tested at the top of the loop, the do-while loop checks its condition at the bottom of the loop. This means that a do-while loop will always execute at least once. The general form of the do-while loop is

```
do {
    statements;
} while(condition);
```

Although the braces are not necessary when only one statement is present, they are often used to improve readability of the do-while construct, thus preventing confusion with the while. The do-while loop executes as long as the conditional expression is true.

The following program loops until the user enters the letter q.

```
// Demonstrate the do-while loop.
class DWDemo {
    public static void main(String args[])
        throws java.io.IOException {

        char ch;

        do {
            System.out.print("Press a key followed by ENTER: ");
            ch = (char) System.in.read(); // get a char
```
Using a do-while loop, we can further improve the guessing game program from earlier in this module. This time, the program loops until you guess the letter.

```java
// Guess the letter game, 4th version.
class Guess4 {
    public static void main(String args[])
        throws java.io.IOException {

        char ch, answer = 'K';

        do {
            System.out.println("I'm thinking of a letter between A and Z.");
            System.out.print("Can you guess it: ");

            // read a letter, but skip cr/lf
            do {
                ch = (char) System.in.read(); // get a char
            } while(ch == '
' | ch == '');

            if(ch == answer) System.out.println("** Right **");
            else {
                System.out.print("...Sorry, you're ");
                if(ch < answer) System.out.println("too low");
                else System.out.println("too high");
                System.out.println("Try again!
");
            }
        } while(answer != ch);
    }
}
```

Here is a sample run:

I'm thinking of a letter between A and Z.
Can you guess it: A
...Sorry, you're too low
Try again!
I'm thinking of a letter between A and Z.
Can you guess it: Z
...Sorry, you're too high
Try again!

I'm thinking of a letter between A and Z.
Can you guess it: K
** Right **

Notice one other thing of interest in this program. The do-while loop shown here obtains the next character, skipping over any carriage return and line feed characters that might be in the input stream:

```java
// read a letter, but skip cr/lf
do {
    ch = (char) System.in.read(); // get a char
} while(ch == '\n' | ch == '\r');
```

Here is why this loop is needed: As explained earlier, System.in is line buffered—you have to press ENTER before characters are sent. Pressing ENTER causes a carriage return and a line feed character to be generated. These characters are left pending in the input buffer. This loop discards those characters by continuing to read input until neither is present.

**Progress Check**

1. What is the main difference between the while and the do-while loops?

2. The condition controlling the while can be of any type. True or False?

---

1. The while checks its condition at the top of the loop. The do-while checks its condition at the bottom of the loop. Thus, a do-while will always execute at least once.
2. False. The condition must be of type boolean.
**Project 3-2** Improve the Java Help System

This project expands on the Java help system that was created in Project 3-1. This version adds the syntax for the `for`, `while`, and `do-while` loops. It also checks the user’s menu selection, looping until a valid response is entered.

**Step by Step**

1. Copy `Help.java` to a new file called `Help2.java`.

2. Change the portion of the program that displays the choices so that it uses the loop shown here:

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

   Notice that a nested `do-while` loop is used to discard any spurious carriage return or line feed characters that may be present in the input stream. After making this change, the program will loop, displaying the menu until the user enters a response that is between 1 and 5.

3. Expand the `switch` statement to include the `for`, `while`, and `do-while` loops, as shown here:

   ```java
switch(choice) {
   case '1':
       System.out.println("The if:
");
       System.out.println("if(condition) statement;");  
       System.out.println("else statement; ");
   break;
```

(continued)
case '2':
    System.out.println("The switch:
");
    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 for:
");
    System.out.println("for(init; condition; iteration) ");
    System.out.println(" statement;");
    break;

case '4':
    System.out.println("The while:
");
    System.out.println("while(condition) statement;");
    break;

case '5':
    System.out.println("The do-while:
");
    System.out.println("do {");
    System.out.println("  statement; ");
    System.out.println("} while (condition); ");
    break;
}

Notice that no default statement is present in this version of the switch. Since the menu loop ensures that a valid response will be entered, it is no longer necessary to include a default statement to handle an invalid choice.

4. Here is the entire Help2.java program listing:

/*
 * Project 3-2

   An improved Help system that uses a do-while to process a menu selection.
 *
 class Help2 {
   public static void main(String args[])
     throws java.io.IOException {
       char choice;

       do {
         System.out.println("Help on:");

Team-Fly®
System.out.println("  1. if");
System.out.println("  2. switch");
System.out.println("  3. for");
System.out.println("  4. while");
System.out.println("  5. do-while
");
System.out.print("Choose one: ");
do {
    choice = (char) System.in.read();
} while(choice == '\n' | choice == '\r');
} 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 for:\n");
    System.out.println("for(int; condition; iteration)" );
    System.out.println(" statement;" );
    break;
case '4':
    System.out.println("The while:\n");
    System.out.println("while(condition) statement;" );
    break;
case '5':
    System.out.println("The do-while:\n");
    System.out.println("do (" );
    System.out.println(" statement;" );
    System.out.println(" } while (condition);" );
    break;
}
Use break to Exit a Loop

It is possible to force an immediate exit from a loop, bypassing any remaining code in the body of the loop and the loop’s conditional test, by using the `break` statement. 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 BreakDemo {
  public static void main(String args[]) {

    int num;

    num = 100;

    // loop while i-squared is less than num
    for(int i=0; i < num; i++) {
      if(i*i >= num) break; // terminate loop if i*i >= 100
      System.out.print(i + " ");
    }

    System.out.println("Loop complete.");
  }
}
```

This program generates the following output:

```
0 1 2 3 4 5 6 7 8 9 Loop complete.
```

As you can see, although the `for` loop is designed to run from 0 to `num` (which in this case is 100), the `break` statement causes it to terminate early, when `i` squared is greater than or equal to `num`.

The `break` statement can be used with any of Java’s loops, including intentionally infinite loops. For example, the following program simply reads input until the user types the letter q.

```java
// Read input until a q is received.
class Break2 {
  public static void main(String args[]) throws java.io.IOException {

    char ch;

    for( ; ; ) { // "infinite" loop
      ch = (char) System.in.read(); // get a char
      if(ch == 'q') break; // terminate this "infinite" loop
    }
  }
}
```
When used inside a set of nested loops, the `break` statement will break out of only the innermost loop. For example:

```java
// Using break with nested loops.
class Break3 {
    public static void main(String args[]) {
        for(int i=0; i<3; i++) {
            System.out.println("Outer loop count: "+ i);
            System.out.print("    Inner loop count: ");

            int t = 0;
            while(t < 100) {
                if(t == 10) break; // terminate loop if t is 10
                System.out.print(t + " ");
                t++;
            }
            System.out.println();
        }
        System.out.println("Loops complete.");
    }
}
```

This program generates the following output:

```
Outer loop count: 0
    Inner loop count: 0 1 2 3 4 5 6 7 8 9
Outer loop count: 1
    Inner loop count: 0 1 2 3 4 5 6 7 8 9
Outer loop count: 2
    Inner loop count: 0 1 2 3 4 5 6 7 8 9
Loops complete.
```

As you can see, the `break` statement in the inner loop causes the termination of only 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 destructure your code. Second, the `break` that terminates a `switch` statement affects only that `switch` statement and not any enclosing loops.
Critical Skill 3.8

Use break as a Form of goto

In addition to its uses with the switch statement and loops, the break statement can be employed by itself to provide a “civilized” form of the goto statement. Java does not have a goto statement, because it provides an unstructured way to alter the flow of program execution. Programs that make extensive use of the goto are usually hard to understand and hard to maintain. There are, however, a few places where the goto is a useful and legitimate device. For example, the goto can be helpful when 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 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:

break label;

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

To name a block, put a label at the start of it. The block being labeled can be a stand-alone block, or a statement that has a block as its target. 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.

```java
// Using break with a label.
class Break4 {
    public static void main(String args[]) {
        int i;

        for(i=1; i<4; i++) {
            one: {
                two: {
                    three: {
                        System.out.println("ni is " + i);
                    }
                }
            }
        }
    }
}
```

The labeled break statement allows you to break out of one or more blocks of code, providing a more structured way to alter the flow of program execution.
The output from the program is shown here:

i is 1
After block one.

i is 2
After block two.
After block one.

i is 3
After block three.
After block two.
After block one.
After for.

Let’s look closely at the program to understand precisely why this output is produced. When \( i \) is 1, the first \texttt{if} statement succeeds, causing a \texttt{break} to the end of the block of code defined by label \texttt{one}. This causes \texttt{After block one.} to print. When \( i \) is 2, the second \texttt{if} succeeds, causing control to be transferred to the end of the block labeled by \texttt{two}. This causes the messages \texttt{After block two.} and \texttt{After block one.} to be printed, in that order. When \( i \) is 3, the third \texttt{if} succeeds, and control is transferred to the end of the block labeled by \texttt{three}. Now, all three messages are displayed.

Here is another example. This time, \texttt{break} is being used to jump outside of a series of nested \texttt{for} loops. When the \texttt{break} statement in the inner loop is executed, program control
jumps to the end of the block defined by the outer for loop, which is labeled by done. This causes the remainder of all three loops to be bypassed.

// Another example of using break with a label.
class Break5 {
    public static void main(String args[]) {
        done:
            for(int i=0; i<10; i++) {
                for(int j=0; j<10; j++) {
                    for(int k=0; k<10; k++) {
                        System.out.println(k + " ");
                        if(k == 5) break done; // jump to done
                    }
                    System.out.println("After k loop"); // won't execute
                }
                System.out.println("After j loop"); // won't execute
            }
            System.out.println("After i loop");
    }
}

The output from the program is shown here:

0
1
2
3
4
5
After i loop

Precisely where you put a label is very important—especially when working with loops. For example, consider the following program:

// Where you put a label is important.
class Break6 {
    public static void main(String args[]) {
        int x=0, y=0;

        // here, put label before for statement.
        stop1: for(x=0; x < 5; x++) {
            for(y = 0; y < 5; y++) {


if(y == 2) break stop1;
    System.out.println("x and y: "+x+" "+y);
}
}

System.out.println();

// now, put label immediately before {
for(x=0; x < 5; x++)
    stop2: {
        for(y = 0; y < 5; y++) {
            if(y == 2) break stop2;
            System.out.println("x and y: "+x+" "+y);
        }
    }
}

The output from this program is shown here:

  x and y: 0 0
  x and y: 0 1

  x and y: 0 0
  x and y: 0 1
  x and y: 1 0
  x and y: 1 1
  x and y: 2 0
  x and y: 2 1
  x and y: 3 0
  x and y: 3 1
  x and y: 4 0
  x and y: 4 1

In the program, both sets of nested loops are the same except for one point. In the first set, the label precedes the outer for loop. In this case, when the break executes, it transfers control to the end of the entire for block, skipping the rest of the outer loop’s iterations. In the second set, the label precedes the outer for’s opening curly brace. Thus, when break stop2 executes, control is transferred to the end of the outer for’s block, causing the next iteration to occur.
Keep in mind that you cannot **break** to any label that 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 to that block.

**Ask the Expert**

**Q:** You say that the **goto** is unstructured and that the break with a label offers a better alternative. But really, doesn’t breaking to a label, which might be many lines of code and levels of nesting removed from the **break**, also destructure code?

**A:** The short answer is yes! However, in those cases in which a jarring change in program flow is required, breaking to a label still retains some structure. A **goto** has none!

**Critical Skill**

**3.9 Use continue**

It is possible to force an early iteration of a loop, bypassing the loop’s normal control structure. This is accomplished using **continue**. The **continue** statement forces the next iteration of the loop to take place, skipping any code between itself and the conditional expression that controls the loop. Thus, **continue** is essentially the complement of **break**. For example, the following program uses **continue** to help print the even numbers between 0 and 100.
// Use continue.
class ContDemo {
    public static void main(String args[]) {
        int i;

        // print even numbers between 0 and 100
        for(i = 0; i<=100; i++) {
            if((i%2) != 0) continue; // iterate
            System.out.println(i);
        }
    }
}

Only even numbers are printed, because an odd one will cause the loop to iterate early, bypassing the call to println().

In while and do-while loops, a continue statement will cause control to go directly to the conditional expression and then continue the looping process. In the case of the for, the iteration expression of the loop is evaluated, then the conditional expression is executed, and then the loop continues.

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 with a label:

// Use continue with a label.
class ContToLabel {
    public static void main(String args[]) {

        outerloop:
        for(int i=1; i < 10; i++) {
            System.out.print("\nOuter loop pass " + i + ", Inner loop: ");
            for(int j = 1; j < 10; j++) {
                if(j == 5) continue outerloop; // continue outer loop
                System.out.print(j);
            }
        }
    }
}

The output from the program is shown here:

Outer loop pass 1, Inner loop: 1234
Outer loop pass 2, Inner loop: 1234
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As the output shows, when the `continue` executes, control passes to the outer loop, skipping the remainder of the inner loop.

Good uses of `continue` are rare. One reason is that Java provides a rich set of loop statements that fit most applications. However, for those special circumstances in which early iteration is needed, the `continue` statement provides a structured way to accomplish it.

Progress Check

1. Within a loop, what happens when a `break` (with no label) is executed?
2. What happens when a `break` with a label is executed?
3. What does `continue` do?

1. Within a loop, a `break` without a label causes immediate termination of the loop. Execution resumes at the first line of code after the loop.
2. When a labeled `break` is executed, execution resumes at the end of the labeled block.
3. The `continue` statement causes a loop to iterate immediately, bypassing any remaining code. If the `continue` includes a label, the labeled loop is continued.
Project 3-3  Finish the Java Help System

This project puts the finishing touches on the Java help system that was created in the previous projects. This version adds the syntax for break and continue. It also allows the user to request the syntax for more than one statement. It does this by adding an outer loop that runs until the user enters q as a menu selection.

Step by Step

1. Copy Help2.java to a new file called Help3.java.

2. Surround all of the program code with an infinite for loop. Break out of this loop, using break, when a letter q is entered. Since this loop surrounds all of the program code, breaking out of this loop causes the program to terminate.

3. Change the menu loop as shown here:

   ```java
   do {
     System.out.println("Help on:");
     System.out.println("  1. if");
     System.out.println("  2. switch");
     System.out.println("  3. for");
     System.out.println("  4. while");
     System.out.println("  5. do-while");
     System.out.println("  6. break");
     System.out.println("  7. continue\n");
     System.out.print("Choose one (q to quit): ");
     do {
       choice = (char) System.in.read();
     } while(choice == '\n' | choice == '\r');
   } while( choice < '1' | choice > '7' & choice != 'q');
   ```

   Notice that this loop now includes the break and continue statements. It also accepts the letter q as a valid choice.

4. Expand the switch statement to include the break and continue statements, as shown here:

   ```java
   case '6':
     System.out.println("The break:\n");
     System.out.println("break; or break label;");
     break;
   case '7':
     System.out.println("The continue:\n");
     System.out.println("continue; or continue label;");
     break;
   ```

   (continued)
5. Here is the entire Help3.java program listing:

    /*
     * Project 3-3
     *
     * The finished Java statement Help system
     * that processes multiple requests.
     */
    class Help3 {
    public static void main(String args[])
        throws java.io.IOException {
        char choice;

        for(;;) {
            do {
                System.out.println("Help on:");
                System.out.println("  1. if");
                System.out.println("  2. switch");
                System.out.println("  3. for");
                System.out.println("  4. while");
                System.out.println("  5. do-while");
                System.out.println("  6. break");
                System.out.println("  7. continue
");
                System.out.print("Choose one (q to quit): ");
                do {
                    choice = (char) System.in.read();
                } while(choice == 'n' | choice == 'r');
            } while( choice < '1' | choice > '7' & choice != 'q');

            if(choice == 'q') break;

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

            switch(choice) {
                case '1':
                    System.out.println("The if:\n");
                    System.out.println("if(condition) statement;\n");
                    System.out.println("else statement;\n");
                    break;
                case '2':
                    System.out.println("The switch:\n");
                    System.out.println("switch(expression) {\n");
                    System.out.println("  case constant:\n");
                    System.out.println("    statement sequence\n");
                    System.out.println("  break;\n");
                    System.out.println("  // ...\n");
                    System.out.println("}\n");
                    break;
        }
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```java
case '3':
    System.out.println("The for:
    System.out.print("for(init; condition; iteration)\n")
    System.out.println(" statement;")
    break;

    case '4':
    System.out.println("The while:
    System.out.println("while(condition) statement;")
    break;

    case '5':
    System.out.println("The do-while:
    System.out.println("do {
    System.out.println("  statement;")
    System.out.println("} while (condition);")
    break;

    case '6':
    System.out.println("The break:
    System.out.println("break; or break label;")
    break;

    case '7':
    System.out.println("The continue:
    System.out.println("continue; or continue label;")
    break;
}
    System.out.println();

6. Here is a sample run:

Help on:
1. if
2. switch
3. for
4. while
5. do-while
6. break
7. continue

Choose one (q to quit): 1

The if:

if(condition) statement;
else statement;

Help on:

(continued)
```
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Choose one (q to quit): 6

The break:

break; or break label;

Help on:
1. if
2. switch
3. for
4. while
5. do-while
6. break
7. continue

Choose one (q to quit): q

CRITICAL SKILL
3.10 Nested Loops

As you have seen in some of the preceding examples, one loop can be nested inside of another. Nested loops are used to solve a wide variety of programming problems and are an essential part of programming. So, before leaving the topic of Java's loop statements, let's look at one more nested loop example. The following program uses a nested for loop to find the factors of the numbers from 2 to 100.

```java
/*
   Use nested loops to find factors of numbers
   between 2 and 100.
*/
class FindFac {
    public static void main(String args[]) {
        for(int i=2; i <= 100; i++) {
            System.out.print("Factors of " + i + ": ");
            for(int j = 2; j < i; j++)
                if((i%j) == 0) System.out.print(j + " ");
            System.out.println();
        }
    }
}
```
Here is a portion of the output produced by the program:

Factors of 2:
Factors of 3:
Factors of 4: 2
Factors of 5:
Factors of 6: 2 3
Factors of 7:
Factors of 8: 2 4
Factors of 9: 3
Factors of 10: 2 5
Factors of 11:
Factors of 12: 2 3 4 6
Factors of 13:
Factors of 14: 2 7
Factors of 15: 3 5
Factors of 16: 2 4 8
Factors of 17:
Factors of 18: 2 3 6 9
Factors of 19:
Factors of 20: 2 4 5 10

In the program, the outer loop runs \( i \) from 2 through 100. The inner loop successively tests all numbers from 2 up to \( i \), printing those that evenly divide \( i \). Extra challenge: The preceding program can be made more efficient. Can you see how? (Hint: the number of iterations in the inner loop can be reduced.)

Module 3 Mastery Check

1. Write a program that reads characters from the keyboard until a period is received. Have the program count the number of spaces. Report the total at the end of the program.

2. Show the general form of the `if-else-if` ladder.

3. Given
   ```java
   if(x < 10)
       if(y > 100) {
           if(!done) x = z;
           else y = z;
       }
   else System.out.println("error"); // what if?
   ```
   to what `if` does the last `else` associate?
4. Show the for statement for a loop that counts from 1000 to 0 by −2.

5. Is the following fragment valid?

```java
for(int i = 0; i < num; i++)
    sum += i;

count = i;
```

6. Explain what break does. Be sure to explain both of its forms.

7. In the following fragment, after the break statement executes, what is displayed?

```java
for(i = 0; i < 10; i++) {
    while(running) {
        if(x<y) break;
        // ...
    }
    System.out.println("after while");
}
System.out.println("After for");
```

8. What does the following fragment print?

```java
for(int i = 0; i<10; i++) {
    System.out.print(i + " ");
    if((i%2) == 0) continue;
    System.out.println();
}
```

9. The iteration expression in a for loop need not always alter the loop control variable by a fixed amount. Instead, the loop control variable can change in any arbitrary way. Using this concept, write a program that uses a for loop to generate and display the progression 1, 2, 4, 8, 16, 32, and so on.

10. The ASCII lowercase letters are separated from the uppercase letters by 32. Thus, to convert a lowercase letter to uppercase, subtract 32 from it. Use this information to write a program that reads characters from the keyboard. Have it convert all lowercase letters to uppercase, and all uppercase letters to lowercase, displaying the result. Make no changes to any other character. Have the program stop when the user presses period. At the end, have the program display the number of case changes that have taken place.

11. What is an infinite loop?

12. When using break with a label, must the label be on a block that contains the break?
Module 4

Introducing Classes, Objects, and Methods

CRITICAL SKILLS

4.1 Know the fundamentals of the class
4.2 Understand how objects are created
4.3 Understand how reference variables are assigned
4.4 Create methods, return values, and use parameters
4.5 Use the return keyword
4.6 Return a value from a method
4.7 Add parameters to a method
4.8 Utilize constructors
4.9 Create parameterized constructors
4.10 Understand new
4.11 Understand garbage collection and finalizers
4.12 Use the this keyword
Before you can go much further in your study of Java, you need to learn about the class. The class is the essence of Java. It is the foundation upon which the entire Java language is built because the class defines the nature of an object. As such, the class forms the basis for object-oriented programming in Java. Within a class are defined data and code that acts upon that data. The code is contained in methods. Because classes, objects, and methods are fundamental to Java, they are introduced in this module. Having a basic understanding of these features will allow you to write more sophisticated programs and better understand certain key Java elements described in the following module.

CRITICAL SKILL

4.1 Class Fundamentals

Since all Java program activity occurs within a class, we have been using classes since the start of this book. Of course, only extremely simple classes have been used, and we have not taken advantage of the majority of their features. As you will see, classes are substantially more powerful than the limited ones presented so far.

Let’s begin by reviewing the basics. A class is a template that defines the form of an object. It specifies both the data and the code that will operate on that data. Java uses a class specification to construct objects. Objects are instances of a class. Thus, a class is essentially a set of plans that specify how to build an object. It is important to be clear on one issue: a class is a logical abstraction. It is not until an object of that class has been created that a physical representation of that class exists in memory.

One other point: recall that the methods and variables that constitute a class are called members of the class. The data members are also referred to as instance variables.

The General Form of a Class

When you define a class, you declare its exact form and nature. You do this by specifying the instance variables that it contains and the methods that operate on them. Although very simple classes might contain only methods or only instance variables, most real-world classes contain both.

A class is created by using the keyword class. The general form of a class definition is shown here:

class classname  {
    // declare instance variables
    type var1;
    type var2;
    // ...
    type varN;

    // declare methods
    type method1(parameters) {

Although there is no syntactic rule that enforces it, a well-designed class should define one and only one logical entity. For example, a class that stores names and telephone numbers will not normally also store information about the stock market, average rainfall, sunspot cycles, or other unrelated information. The point here is that a well-designed class groups logically connected information. Putting unrelated information into the same class will quickly destruct your code!

Up to this point, the classes that we have been using have only had one method: `main()`. Soon you will see how to create others. However, notice that the general form of a class does not specify a `main()` method. A `main()` method is required only if that class is the starting point for your program. Also, applets don’t require a `main()`.

### Defining a Class

To illustrate classes we will develop a class that encapsulates information about vehicles, such as cars, vans, and trucks. This class is called `Vehicle`, and it will store three items of information about a vehicle: the number of passengers that it can carry, its fuel capacity, and its average fuel consumption (in miles per gallon).

The first version of `Vehicle` is shown next. It defines three instance variables: `passengers`, `fuelcap`, and `mpg`. Notice that `Vehicle` does not contain any methods. Thus, it is currently a data-only class. (Subsequent sections will add methods to it.)

```java
class Vehicle {
    int passengers; // number of passengers
    int fuelcap;    // fuel capacity in gallons
    int mpg;        // fuel consumption in miles per gallon
}
```

A **class** definition creates a new data type. In this case, the new data type is called `Vehicle`. You will use this name to declare objects of type `Vehicle`. Remember that a **class** declaration is only a type description; it does not create an actual object. Thus, the preceding code does not cause any objects of type `Vehicle` to come into existence.
To actually create a **Vehicle** object, you will use a statement like the following:

```java
Vehicle minivan = new Vehicle(); // create a Vehicle object called minivan
```

After this statement executes, **minivan** will be an instance of **Vehicle**. Thus, it will have “physical” reality. For the moment, don’t worry about the details of this statement.

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 **Vehicle** object will contain its own copies of the instance variables **passengers**, **fuelcap**, and **mpg**. To access these variables, you will use the dot (.) operator. The *dot operator* links the name of an object with the name of a member. The general form of the dot operator is shown here:

```
object.member
```

Thus, the object is specified on the left, and the member is put on the right. For example, to assign the **fuelcap** variable of **minivan** the value 16, use the following statement:

```java
minivan.fuelcap = 16;
```

In general, you can use the dot operator to access both instance variables and methods.

Here is a complete program that uses the **Vehicle** class:

```java
/* A program that uses the Vehicle class.

Call this file VehicleDemo.java
*/

class Vehicle {
    int passengers; // number of passengers
    int fuelcap;    // fuel capacity in gallons
    int mpg;        // fuel consumption in miles per gallon
}

// This class declares an object of type Vehicle.
class VehicleDemo {
    public static void main(String args[]) {
        Vehicle minivan = new Vehicle();
        int range;

        // assign values to fields in minivan
        minivan.passengers = 7;
        minivan.fuelcap = 16; Notice the use of the dot operator to access a member.
        minivan.mpg = 21;

        // compute the range assuming a full tank of gas
        range = minivan.fuelcap * minivan.mpg;
    }
}
```
System.out.println("Minivan can carry " + minivan.passengers + 
    " with a range of " + range);
}
}

You should call the file that contains this program VehicleDemo.java because the main() method is in the class called VehicleDemo, not the class called Vehicle. When you compile this program, you will find that two .class files have been created, one for Vehicle and one for VehicleDemo. The Java compiler automatically puts each class into its own .class file. It is not necessary for both the Vehicle and the VehicleDemo class to be in the same source file. You could put each class in its own file, called Vehicle.java and VehicleDemo.java, respectively.

To run this program, you must execute VehicleDemo.class. The following output is displayed:

Minivan can carry 7 with a range of 336

Before moving on, let’s review a fundamental principle: each object has its own copies of the instance variables defined by its class. Thus, the contents of the variables in one object can differ from the contents of the variables in another. There is no connection between the two objects except for the fact that they are both objects of the same type. For example, if you have two Vehicle objects, each has its own copy of passengers, fuelcap, and mpg, and the contents of these can differ between the two objects. The following program demonstrates this fact. (Notice that the class with main() is now called TwoVehicles.)

// This program creates two Vehicle objects.

class Vehicle {
    int passengers; // number of passengers
    int fuelcap;    // fuel capacity in gallons
    int mpg;        // fuel consumption in miles per gallon
}

// This class declares an object of type Vehicle.

class TwoVehicles {
    public static void main(String args[]) {
        Vehicle minivan = new Vehicle();
        Vehicle sportscar = new Vehicle();

        int range1, range2;

        // assign values to fields in minivan
        minivan.passengers = 7;
        minivan.fuelcap = 16;
        minivan.mpg = 21;

        // assign values to fields in sportscar
        sportscar.passengers = 2;
        sportscar.fuelcap = 10;
        sportscar.mpg = 30;

        // display properties of minivan
        System.out.println("Minivan can carry ");
        System.out.println(minivan.passengers);
        System.out.println(" with a range of ");
        System.out.println(minivan.fuelcap);
        System.out.println(" miles per gallon");
    }
}

Remember, minivan and sportscar refer to separate objects.
// assign values to fields in sportscar
sportscar.passengers = 2;
sportscar.fuelcap = 14;
sportscar.mpg = 12;

// compute the ranges assuming a full tank of gas
range1 = minivan.fuelcap * minivan.mpg;
range2 = sportscar.fuelcap * sportscar.mpg;

System.out.println("Minivan can carry " + minivan.passengers + " with a range of " + range1);
System.out.println("Sportscar can carry " + sportscar.passengers + " with a range of " + range2);

The output produced by this program is shown here:

Minivan can carry 7 with a range of 336
Sportscar can carry 2 with a range of 168

As you can see, minivan’s data is completely separate from the data contained in sportscar. The following illustration depicts this situation.

As you can see, minivan’s data is completely separate from the data contained in sportscar.

Progress Check

1. A class contains what two things?

2. What operator is used to access the members of a class through an object?

3. Each object has its own copies of the class’s _____________.

1. Code and data. In Java, this means methods and instance variables.
2. The dot operator.
3. instance variables
How Objects Are Created

In the preceding programs, the following line was used to declare an object of type Vehicle:

```java
Vehicle minivan = new Vehicle();
```

This declaration performs two functions. First, it declares a variable called `minivan` of the class type `Vehicle`. This variable does not define an object. Instead, it is simply a variable that can refer to an object. Second, the declaration creates a physical copy of the object and assigns to `minivan` a reference to that object. This is done by 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, more or less, the address in memory of the object allocated by `new`. This reference is then stored in a variable. Thus, in Java, all class objects must be dynamically allocated.

The two steps combined in the preceding statement can be rewritten like this to show each step individually:

```java
Vehicle minivan; // declare reference to object
minivan = new Vehicle(); // allocate a Vehicle object
```

The first line declares `minivan` as a reference to an object of type `Vehicle`. Thus, `minivan` is a variable that can refer to an object, but it is not an object, itself. At this point, `minivan` contains the value `null`, which means that it does not refer to an object. The next line creates a new `Vehicle` object and assigns a reference to it to `minivan`. Now, `minivan` is linked with an object.

Reference Variables and Assignment

In an assignment operation, object reference variables act differently than do variables of a simple type, such as `int`. When you assign one simple-type variable to another, the situation is straightforward. The variable on the left receives a copy of the value of the variable on the right. When you assign an object reference variable to another, the situation is a bit more complicated because you are changing the object that the reference variable refers to. The effect of this difference can cause some counterintuitive results. For example, consider the following fragment:

```java
Vehicle car1 = new Vehicle();
Vehicle car2 = car1;
```

At first glance, it is easy to think that `car1` and `car2` refer to different objects, but this is not the case. Instead, `car1` and `car2` will both refer to the same object. The assignment of `car1` to
car2 simply makes car2 refer to the same object as does car1. Thus, the object can be acted upon by either car1 or car2. For example, after the assignment

car1.mpg = 26;

executes, both of these println() statements

System.out.println(car1.mpg);
System.out.println(car2.mpg);

display the same value: 26.

Although car1 and car2 both refer to the same object, they are not linked in any other way. For example, a subsequent assignment to car2 simply changes the object to which car2 refers. For example:

Vehicle car1 = new Vehicle();
Vehicle car2 = car1;
Vehicle car3 = new Vehicle();

car2 = car3; // now car2 and car3 refer to the same object.

After this sequence executes, car2 refers to the same object as car3. The object referred to by car1 is unchanged.

Progress Check

1. Explain what occurs when one object reference variable is assigned to another.

2. Assuming a class called MyClass, show how an object called ob is created.

Methods

As explained, instance variables and methods are the constituents of classes. So far, the Vehicle class contains data, but no methods. Although data-only classes are perfectly valid, most classes will have methods. Methods are subroutines that manipulate the data defined by the class and, in many cases, provide access to that data. In most cases, other parts of your program will interact with a class through its methods.

1. When one object reference variable is assigned to another object reference variable, both variables will refer to the same object. A copy of the object is not made.

2. MyClass ob = new MyClass();
A method contains one or more statements. In well-written Java code, each method performs only one task. Each method has a name, and it is this name that is used to call the method. In general, you can give a method whatever name you please. However, remember that \texttt{main()} is reserved for the method that begins execution of your program. Also, don’t use Java’s keywords for method names.

When denoting methods in text, this book has used and will continue to use a convention that has become common when writing about Java. A method will have parentheses after its name. For example, if a method’s name is \texttt{getval}, it will be written \texttt{getval()} when its name is used in a sentence. This notation will help you distinguish variable names from method names in this book.

The general form of a method is shown here:

\begin{verbatim}
ret-type name(parameter-list) {
   // body of method
}
\end{verbatim}

Here, \textit{ret-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 \textit{arguments} passed to the method when it is called. If the method has no parameters, the parameter list will be empty.

### Adding a Method to the Vehicle Class

As just explained, the methods of a class typically manipulate and provide access to the data of the class. With this in mind, recall that \texttt{main()} in the preceding examples computed the range of a vehicle by multiplying its fuel consumption rate by its fuel capacity. While technically correct, this is not the best way to handle this computation. The calculation of a vehicle’s range is something that is best handled by the \texttt{Vehicle} class itself. The reason for this conclusion is easy to understand: the range of a vehicle is dependent upon the capacity of the fuel tank and the rate of fuel consumption, and both of these quantities are encapsulated by \texttt{Vehicle}. By adding a method to \texttt{Vehicle} that computes the range, you are enhancing its object-oriented structure.

To add a method to \texttt{Vehicle}, specify it within \texttt{Vehicle}’s declaration. For example, the following version of \texttt{Vehicle} contains a method called \texttt{range()} that displays the range of the vehicle.

\begin{verbatim}
// Add range to Vehicle.

class Vehicle {
   int passengers; // number of passengers
   int fuelcap;    // fuel capacity in gallons
}
\end{verbatim}
int mpg;        // fuel consumption in miles per gallon

// Display the range.
void range() {
    System.out.println("Range is " + fuelcap * mpg);
}
}

class AddMeth {
public static void main(String args[]) {
    Vehicle minivan = new Vehicle();
    Vehicle sportscar = new Vehicle();

    int range1, range2;

    // assign values to fields in minivan
    minivan.passengers = 7;
    minivan.fuelcap = 16;
    minivan.mpg = 21;

    // assign values to fields in sportscar
    sportscar.passengers = 2;
    sportscar.fuelcap = 14;
    sportscar.mpg = 12;

    System.out.print("Minivan can carry " + minivan.passengers + ". ");

    minivan.range(); // display range of minivan

    System.out.print("Sportscar can carry " + sportscar.passengers + ". ");

    sportscar.range(); // display range of sportscar.
}
}

This program generates the following output:

Minivan can carry 7. Range is 336
Sportscar can carry 2. Range is 168

Let’s look at the key elements of this program, beginning with the range() method itself. The first line of range() is

void range() {
This line declares a method called `range` that has no parameters. Its return type is `void`. Thus, `range()` does not return a value to the caller. The line ends with the opening curly brace of the method body.

The body of `range()` consists solely of this line:

```java
System.out.println("Range is " + fuelcap * mpg);
```

This statement displays the range of the vehicle by multiplying `fuelcap` by `mpg`. Since each object of type `Vehicle` has its own copy of `fuelcap` and `mpg`, when `range()` is called, the range computation uses the calling object’s copies of those variables.

The `range()` method ends when its closing curly brace is encountered. This causes program control to transfer back to the caller.

Next, look closely at this line of code from inside `main()`:

```java
minivan.range();
```

This statement invokes the `range()` method on `minivan`. That is, it calls `range()` relative to the `minivan` object, using the object’s name followed by the dot operator. When a method is called, program control is transferred to the method. When the method terminates, control is transferred back to the caller, and execution resumes with the line of code following the call.

In this case, the call to `minivan.range()` displays the range of the vehicle defined by `minivan`. In similar fashion, the call to `sportscar.range()` displays the range of the vehicle defined by `sportscar`. Each time `range()` is invoked, it displays the range for the specified object.

There is something very important to notice inside the `range()` method: the instance variables `fuelcap` and `mpg` 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 `fuelcap` and `mpg` inside `range()` implicitly refer to the copies of those variables found in the object that invokes `range()`.

### Critical Skill

#### 4.5 Returning from a Method

In general, there are two conditions that cause a method to return—first, as the `range()` method in the preceding example shows, when the method’s closing curly brace is encountered. The second is when a `return` statement is executed. There are two forms of `return—one for use in `void` methods (those that do not return a value) and one for returning values. The first form is examined here. The next section explains how to return values.
In a **void** method, you can cause the immediate termination of a method by using this form of **return**:

```java
return ;
```

When this statement executes, program control returns to the caller, skipping any remaining code in the method. For example, consider this method:

```java
void myMeth() {
    int i;

    for(i=0; i<10; i++) {
        if(i == 5) return; // stop at 5
        System.out.println();
    }
}
```

Here, the **for** loop will only run from 0 to 5, because once `i` equals 5, the method returns.

It is permissible to have multiple return statements in a method, especially when there are two or more routes out of it. For example:

```java
void myMeth() {
    // ...
    if(done) return;
    // ...
    if(error) return;
}
```

Here, the method returns if it is done or if an error occurs. Be careful, however, because having too many exit points in a method can destruct your code; so avoid using them casually. A well-designed method has well-defined exit points.

To review: a **void** method can return in one of two ways—it's closing curly brace is reached, or a **return** statement is executed.

**CRITICAL SKILL 4.6: Returning a Value**

Although methods with a return type of **void** are not rare, most methods will return a value. In fact, the ability to return a value is one of the most useful features of a method. You have already seen one example of a return value: when we used the `sqrt()` function to obtain a square root.
Return values are used for a variety of purposes in programming. In some cases, such as with \texttt{sqrt( )}, the return value contains the outcome of some calculation. In other cases, the return value may simply indicate success or failure. In still others, it may contain a status code. Whatever the purpose, using method return values is an integral part of Java programming.

Methods return a value to the calling routine using this form of \texttt{return}:

\begin{verbatim}
return value;
\end{verbatim}

Here, \texttt{value} is the value returned.

You can use a return value to improve the implementation of \texttt{range( )}. Instead of displaying the range, a better approach is to have \texttt{range( )} compute the range and return this value. Among the advantages to this approach is that you can use the value for other calculations. The following example modifies \texttt{range( )} to return the range rather than displaying it.

\begin{verbatim}
// Use a return value.

class Vehicle {
    int passengers; // number of passengers
    int fuelcap;    // fuel capacity in gallons
    int mpg;        // fuel consumption in miles per gallon

    // Return the range.
    int range() {
        return mpg * fuelcap; // Return the range for a given vehicle.
    }
}

class RetMeth {
    public static void main(String args[]) {
        Vehicle minivan = new Vehicle();
        Vehicle sportscar = new Vehicle();

        int range1, range2;

        // assign values to fields in minivan
        minivan.passengers = 7;
        minivan.fuelcap = 16;
        minivan.mpg = 21;

        // assign values to fields in sportscar
        sportscar.passengers = 2;
        sportscar.fuelcap = 14;
        sportscar.mpg = 12;
    }
}
\end{verbatim}
// get the ranges
range1 = minivan.range();
range2 = sportscar.range();

System.out.println("Minivan can carry " + minivan.passengers + 
    " with range of " + range1 + " Miles");

System.out.println("Sportscar can carry " + sportscar.passengers + 
    " with range of " + range2 + " miles");
}
}

The output is shown here:
Minivan can carry 7 with range of 336 Miles
Sportscar can carry 2 with range of 168 miles

In the program, notice that when range() is called, it is put on the right side of an assignment statement. On the left is a variable that will receive the value returned by range(). Thus, after
range1 = minivan.range();

executes, the range of the minivan object is stored in range1.

Notice that range() now has a return type of int. This means that it will return an integer value to the caller. The return type of a method is important because the type of data returned by a method must be compatible with the return type specified by the method. Thus, if you want a method to return data of type double, its return type must be type double.

Although the preceding program is correct, it is not written as efficiently as it could be. Specifically, there is no need for the range1 or range2 variables. A call to range() can be used in the println() statement directly, as shown here:
System.out.println("Minivan can carry " + minivan.passengers + 
    " with range of " + minivan.range() + " Miles");

In this case, when println() is executed, minivan.range() is called automatically and its value will be passed to println(). Furthermore, you can use a call to range() whenever the range of a Vehicle object is needed. For example, this statement compares the ranges of two vehicles:
if(v1.range() > v2.range()) System.out.println("v1 has greater range");
Using Parameters

It is possible to pass one or more values to a method when the method is called. As explained, a value passed to a method is called an argument. Inside the method, the variable that receives the argument is called a parameter. Parameters are declared inside the parentheses that follow the method’s name. The parameter declaration syntax is the same as that used for variables. A parameter is within the scope of its method, and aside from its special task of receiving an argument, it acts like any other local variable.

Here is a simple example that uses a parameter. Inside the ChkNum class, the method isEven() returns true if the value that it is passed is even. It returns false otherwise. Therefore, isEven() has a return type of boolean.

```java
// A simple example that uses a parameter.

class ChkNum {
    // return true if x is even
    boolean isEven(int x) {
        if((x%2) == 0) return true;
        else return false;
    }
}

class ParmDemo {
    public static void main(String args[]) {
        ChkNum e = new ChkNum();

        if(e.isEven(10)) System.out.println("10 is even.");
        if(e.isEven(9)) System.out.println("9 is even.");
        if(e.isEven(8)) System.out.println("8 is even.");
    }
}
```

Here is the output produced by the program:

```
10 is even.
8 is even.
```

In the program, isEven() is called three times, and each time a different value is passed. Let’s look at this process closely. First, notice how isEven() is called. The argument is
specified between the parentheses. When isEven() is called the first time, it is passed the value 10. Thus, when isEven() begins executing, the parameter x receives the value 10. In the second call, 9 is the argument, and x, then, has the value 9. In the third call, the argument is 8, which is the value that x receives. The point is that the value passed as an argument when isEven() is called is the value received by its parameter, x.

A method can have more than one parameter. Simply declare each parameter, separating one from the next with a comma. For example, the Factor class defines a method called isFactor() that determines whether the first parameter is a factor of the second.

class Factor {
    boolean isFactor(int a, int b) {
        if( (b % a) == 0) return true;
        else return false;
    }
}
class IsFact {
    public static void main(String args[]) {
        Factor x = new Factor();

        if(x.isFactor(2, 20)) System.out.println("2 is factor");
        if(x.isFactor(3, 20)) System.out.println("this won't be displayed");
    }
}

Notice that when isFactor() is called, the arguments are also separated by commas.

When using multiple parameters, each parameter specifies its own type, which can differ from the others. For example, this is perfectly valid:

int myMeth(int a, double b, float c) {
    // ...
}

Adding a Parameterized Method to Vehicle

You can use a parameterized method to add a new feature to the Vehicle class: the ability to compute the amount of fuel needed for a given distance. This new method is called fuelneeded(). This method takes the number of miles that you want to drive and returns the number of gallons of gas required. The fuelneeded() method is defined like this:

double fuelneeded(int miles) {
    return (double) miles / mpg;
}
Notice that this method returns a value of type double. This is useful since the amount of fuel needed for a given distance might not be an even number.

The entire Vehicle class that includes fuelneeded() is shown here:

```java
/*
   Add a parameterized method that computes the fuel required for a given distance.
*/

class Vehicle {
    int passengers; // number of passengers
    int fuelcap;    // fuel capacity in gallons
    int mpg;        // fuel consumption in miles per gallon

    // Return the range.
    int range() {
        return mpg * fuelcap;
    }

    // Compute fuel needed for a given distance.
    double fuelneeded(int miles) {
        return (double) miles / mpg;
    }
}

class CompFuel {
    public static void main(String args[]) {
        Vehicle minivan = new Vehicle();
        Vehicle sportscar = new Vehicle();
        double gallons;
        int dist = 252;

        // assign values to fields in minivan
        minivan.passengers = 7;
        minivan.fuelcap = 16;
        minivan.mpg = 21;

        // assign values to fields in sportscar
        sportscar.passengers = 2;
        sportscar.fuelcap = 14;
        sportscar.mpg = 12;
    }
}
```
gallons = minivan.fuelneeded(dist);

System.out.println("To go " + dist + " miles minivan needs " +
gallons + " gallons of fuel.");

gallons = sportscar.fuelneeded(dist);

System.out.println("To go " + dist + " miles sportscar needs " +
gallons + " gallons of fuel.");

The output from the program is shown here:

To go 252 miles minivan needs 12.0 gallons of fuel.
To go 252 miles sportscar needs 21.0 gallons of fuel.

Progress Check

1. When must an instance variable or method be accessed through an object reference using the dot operator? When can a variable or method be used directly?

2. Explain the difference between an argument and a parameter.

3. Explain the two ways that a method can return to its caller.

1. 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.

2. An argument is a value that is passed to a method when it is invoked. A parameter is a variable defined by a method that receives the value of the argument.

3. A method can be made to return through the use of the return statement. If the method has a void return type, it will also return when its closing curly brace is reached. Non-void methods must return a value, so returning by reaching the closing curly brace is not an option.
Project 4-1  Creating a Help Class

If one were to try to summarize the essence of the class in one sentence, it might be this: a class encapsulates functionality. Of course, sometimes the trick is knowing where one “functionality” ends and another begins. As a general rule, you will want your classes to be the building blocks of your larger application. In order to do this, each class must represent a single functional unit that performs clearly delineated actions. Thus, you will want your classes to be as small as possible—but no smaller! That is, classes that contain extraneous functionality confuse and destructure code, but classes that contain too little functionality are fragmented. What is the balance? It is at this point that the science of programming becomes the art of programming. Fortunately, most programmers find that this balancing act becomes easier with experience.

To begin to gain that experience you will convert the help system from Project 3-3 in the preceding module into a Help class. Let’s examine why this is a good idea. First, the help system defines one logical unit. It simply displays the syntax for Java’s control statements. Thus, its functionality is compact and well defined. Second, putting help in a class is an esthetically pleasing approach. Whenever you want to offer the help system to a user, simply instantiate a help-system object. Finally, because help is encapsulated, it can be upgraded or changed without causing unwanted side effects in the programs that use it.

Step by Step

1. Create a new file called HelpClassDemo.java. To save you some typing, you might want to copy the file from Project 3-3, Help3.java, into HelpClassDemo.java.

2. To convert the help system into a class, you must first determine precisely what constitutes the help system. For example, in Help3.java, there is code to display a menu, input the user’s choice, check for a valid response, and display information about the item selected. The program also loops until the letter q is pressed. If you think about it, it is clear that the menu, the check for a valid response, and the display of the information are integral to the help system. How user input is obtained, and whether repeated requests should be processed, are not. Thus, you will create a class that displays the help information, the help menu, and checks for a valid selection. These methods will be called helpon(), showmenu(), and isvalid(), respectively.

(continued)
3. Create the `helpon()` method as shown here:

```java
void helpon(int what) {
    switch(what) {
    case '1':
        System.out.println("The if:
");
        System.out.println("if(condition) statement;");
        System.out.println("else statement;");
        break;
    case '2':
        System.out.println("The switch:
");
        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 for:
");
        System.out.print("for(init; condition; iteration) ");
        System.out.println(" statement;");
        break;
    case '4':
        System.out.println("The while:
");
        System.out.println("while(condition) statement;");
        break;
    case '5':
        System.out.println("The do-while:
");
        System.out.println("do {");
        System.out.println("    statement;");
        System.out.println("} while (condition);");
        break;
    case '6':
        System.out.println("The break:
");
        System.out.println("break; or break label;");
        break;
    case '7':
        System.out.println("The continue:
");
        System.out.println("continue; or continue label;");
        break;
    }
    System.out.println();
}
```

4. Next, create the `showmenu()` method:

```java
void showmenu() {
    System.out.println("Help on:");
```
5. Create the `isValid()` method, shown here:

```java
boolean isValid(int ch) {
    if (ch < '1' | ch > '7' & ch != 'q') return false;
    else return true;
}
```

6. Assemble the foregoing methods into the `Help` class, shown here:

```java
class Help {
    void helpon(int what) {
        switch(what) {
            case '1':
                System.out.println("The if:
                System.out.println("if(condition) statement;");
                System.out.println("else statement;");
                break;
            case '2':
                System.out.println("The switch:
                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 for:
                System.out.println("for(init; condition; iteration)"");
                System.out.println(" statement;");
                break;
            case '4':
                System.out.println("The while:
                System.out.println("while(condition) statement;");
                break;
            case '5':
                System.out.println("The do-while:
            
```
```
System.out.println("do ");
System.out.println(" statement;");
System.out.println("} while (condition);"));
  break;
  case '6':
    System.out.println("The break:
");
    System.out.println("break; or break label;");
    break;
  case '7':
    System.out.println("The continue:
");
    System.out.println("continue; or continue label;");
    break;
  }
System.out.println();
}

void showmenu() {
  System.out.println("Help on:");
  System.out.println("  1. if");
  System.out.println("  2. switch");
  System.out.println("  3. for");
  System.out.println("  4. while");
  System.out.println("  5. do-while");
  System.out.println("  6. break");
  System.out.println("  7. continue
");
  System.out.print("Choose one (q to quit): ");
}

boolean isvalid(int ch) {
  if(ch < '1' | ch > '7' & ch != 'q') return false;
  else return true;
}

7. Finally, rewrite the main() method from Project 3-3 so that it uses the new Help class. Call this class HelpClassDemo.java. The entire listing for HelpClassDemo.java is shown here:

/*
 Project 4-1

 Convert the help system from Project 3-3 into a Help class.
 */

class Help {
```
void helpon(int what) {
    switch(what) {
    case '1':
        System.out.println("The if:");
        System.out.println("if(condition) statement;") ;
        System.out.println("else statement; ");
        break;
    case '2':
        System.out.println("The switch:");
        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 for:");
        System.out.println("for(init; condition; iteration)");
        System.out.println(" statement; ");
        break;
    case '4':
        System.out.println("The while:");
        System.out.println("while(condition) statement; ");
        break;
    case '5':
        System.out.println("The do-while:");
        System.out.println("do ");
        System.out.println(" statement; ");
        System.out.println("} while {condition}; ");
        break;
    case '6':
        System.out.println("The break:");
        System.out.println("break; or break label; ");
        break;
    case '7':
        System.out.println("The continue:");
        System.out.println("continue; or continue label; ");
        break;
    }
    System.out.println();
}

void showmenu() {
    System.out.println("Help on: ");
}(continued)
System.out.println("  1. if");
System.out.println("  2. switch");
System.out.println("  3. for");
System.out.println("  4. while");
System.out.println("  5. do-while");
System.out.println("  6. break");
System.out.println("  7. continue\n");
System.out.print("Choose one (q to quit): ");

boolean isvalid(int ch) {
    if(ch < '1' | ch > '7' & ch != 'q') return false;
    else return true;
}

class HelpClassDemo {
    public static void main(String args[]) throws java.io.IOException {
        char choice;
        Help hlpobj = new Help();

        for(;;) {
            do {
                hlpobj.showmenu();
                do {
                    choice = (char) System.in.read();
                } while(choice == '\n' | choice == '\r');
            } while( !hlpobj.isvalid(choice) );

            if(choice == 'q') break;

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

            hlpobj.helpon(choice);
        }
    }
}

When you try the program, you will find that it is functionally the same as before. The advantage to this approach is that you now have a help system component that can be reused whenever it is needed.
Constructors

In the preceding examples, the instance variables of each Vehicle object had to be set manually using a sequence of statements, such as:

```java
minivan.passengers = 7;
minivan.fuelcap = 16;
minivan.mpg = 21;
```

An approach like this would never be used in professionally written Java code. Aside from being error prone (you might forget to set one of the fields), there is simply a better way to accomplish this task: the constructor.

A constructor initializes an object when it is created. It has the same name as its class and is syntactically similar to a method. However, constructors have no explicit return type. Typically, you will use a constructor to give initial values to the instance variables defined by the class, or to perform any other startup procedures required to create a fully formed object.

All classes have constructors, whether you define one or not, because Java automatically provides a default constructor that initializes all member variables to zero. However, once you define your own constructor, the default constructor is no longer used.

Here is a simple example that uses a constructor:

```java
// A simple constructor.

class MyClass {
    int x;

    MyClass() { // The constructor for MyClass
        x = 10;
    }
}

class ConsDemo {

    public static void main(String args[]) {
        MyClass t1 = new MyClass();
        MyClass t2 = new MyClass();

        System.out.println(t1.x + " " + t2.x);
    }
}

In this example, the constructor for MyClass is

```
This constructor assigns the instance variable \texttt{x} of \texttt{MyClass} the value 10. This constructor is called by \texttt{new} when an object is created. For example, in the line

\begin{verbatim}
MyClass t1 = new MyClass();
\end{verbatim}

the constructor \texttt{MyClass()} is called on the \texttt{t1} object, giving \texttt{t1.x} the value 10. The same is true for \texttt{t2}. After construction, \texttt{t2.x} has the value 10. Thus, the output from the program is

\begin{verbatim}
10 10
\end{verbatim}

\section*{Critical Skill 4.9 Parameterized Constructors}

In the preceding example, a parameter-less constructor was used. Although this is fine for some situations, most often you will need a constructor that accepts one or more parameters. Parameters are added to a constructor in the same way that they are added to a method: just declare them inside the parentheses after the constructor’s name. For example, here, \texttt{MyClass} is given a parameterized constructor:

\begin{verbatim}
// A parameterized constructor.

class MyClass {
    int x;

    MyClass(int i) {
        x = i;
    }
}

class ParmConsDemo {
    public static void main(String args[]) {
        MyClass t1 = new MyClass(10);
        MyClass t2 = new MyClass(88);

        System.out.println(t1.x + " " + t2.x);
    }
}
\end{verbatim}

The output from this program is shown here:

\begin{verbatim}
10 88
\end{verbatim}

In this version of the program, the \texttt{MyClass()} constructor defines one parameter called \texttt{i}, which is used to initialize the instance variable, \texttt{x}. Thus, when the line

\begin{verbatim}
MyClass t1 = new MyClass(10);
\end{verbatim}

executes, the value 10 is passed to \texttt{i}, which is then assigned to \texttt{x}. 
Adding a Constructor to the Vehicle Class

We can improve the Vehicle class by adding a constructor that automatically initializes the passengers, fuelcap, and mpg fields when an object is constructed. Pay special attention to how Vehicle objects are created.

// Add a constructor.

class Vehicle {
    int passengers; // number of passengers
    int fuelcap;    // fuel capacity in gallons
    int mpg;        // fuel consumption in miles per gallon

    // This is a constructor for Vehicle.
    Vehicle(int p, int f, int m) {
        passengers = p;
        fuelcap = f;
        mpg = m;
    }

    // Return the range.
    int range() {
        return mpg * fuelcap;
    }

    // Compute fuel needed for a given distance.
    double fuelneeded(int miles) {
        return (double) miles / mpg;
    }
}

class VehConsDemo {
    public static void main(String args[]) {

        // construct complete vehicles
        Vehicle minivan = new Vehicle(7, 16, 21);
        Vehicle sportscar = new Vehicle(2, 14, 12);
        double gallons;
        int dist = 252;

        gallons = minivan.fuelneeded(dist);

        System.out.println("To go " + dist + " miles minivan needs " +
                gallons + " gallons of fuel.");
    }
}
gallons = sportscar.fuelneeded(dist);

System.out.println("To go " + dist + " miles sportscar needs " +
gallons + " gallons of fuel.");

Both minivan and sportscar are initialized by the Vehicle() constructor when they are created. Each object is initialized as specified in the parameters to its constructor. For example, in the following line,

Vehicle minivan = new Vehicle(7, 16, 21);

the values 7, 16, and 21 are passed to the Vehicle() constructor when new creates the object. Thus, minivan’s copy of passengers, fuelcap, and mpg will contain the values 7, 16, and 21, respectively. The output from this program is the same as the previous version.

Progress Check

1. What is a constructor, and when is it executed?
2. Does a constructor have a return type?

The new Operator Revisited

Now that you know more about classes and their constructors, let’s take a closer look at the new operator. The new operator has this general form:

class-var = new class-name();

Here, class-var is a variable of the class type being created. The class-name is the name of the class that is being instantiated. The class name followed by parentheses specifies the constructor for the class. If a class does not define its own constructor, new will use the default constructor supplied by Java. Thus, new can be used to create an object of any class type.

1. A constructor is a method that is executed when an object of its class is instantiated. A constructor is used to initialize the object being created.
2. No.
Ask the Expert

Q: Why don’t I need to use new for variables of the simple types, such as int or float?

A: Java’s simple types are not implemented as objects. Rather, because of efficiency concerns, they are implemented as “normal” variables. A variable of a simple type actually contains the value that you have given it. As explained, object variables are references to the object. This layer of indirection (and other object features) adds overhead to an object that is avoided by a simple type.

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 this and other exceptions in Module 9.) 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.

Garbage Collection and Finalizers

As you have seen, objects are dynamically allocated from a pool of free memory by using the new operator. As explained, memory is not infinite, and the free memory can be exhausted. Thus, it is possible for new to fail because there is insufficient free memory to create the desired object. For this reason, a key component of any dynamic allocation scheme is the recovery of free memory from unused objects, making that memory available for subsequent reallocation. In many programming languages, the release of previously allocated memory is handled manually. For example, in C++, you use the delete operator to free memory that was allocated. However, Java uses a different, more trouble-free approach: garbage collection.

Java’s garbage collection system reclaims objects automatically—occurring transparently, behind the scenes, without any programmer intervention. 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 is released. This recycled memory can then be used for a subsequent allocation.

Garbage collection occurs only sporadically during the execution of your program. It will not occur simply because one or more objects exist that are no longer used. For efficiency, the garbage collector will usually run only when two conditions are met: there are objects to recycle, and there is a need to recycle them. Remember, garbage collection takes time, so the Java run-time system does it only when necessary. Thus, you can’t know precisely when garbage collection will take place.
The finalize( ) Method

It is possible to define a method that will be called just before an object’s final destruction by the garbage collector. This method is called finalize( ), and it can be used to ensure that an object terminates cleanly. For example, you might use finalize( ) to make sure that an open file owned by that object is closed.

To add a finalizer to a class, you simply define the finalize( ) method. The Java run time calls that method whenever it is about to recycle an object of that class. Inside the finalize( ) method you will specify those actions that must be performed before an object is destroyed.

The finalize( ) method has this general form:

```java
protected void finalize()
{
  // finalization code here
}
```

Here, the keyword protected is a specifier that prevents access to finalize( ) by code defined outside its class. This and the other access specifiers are explained in Module 6.

It is important to understand that finalize( ) is called just before garbage collection. It is not called when an object goes out of scope, for example. This means that you cannot know when—or even if—finalize( ) will be executed. For example, if your program ends before garbage collection occurs, finalize( ) will not execute. Therefore, it should be used as a “backup” procedure to ensure the proper handling of some resource, or for special-use applications, not as the means that your program uses in its normal operation.

Ask the Expert

**Q:** I know that C++ defines things called destructors, which are automatically executed when an object is destroyed. Is finalize( ) similar to a destructor?

**A:** Java does not have destructors. Although it is true that the finalize( ) method approximates the function of a destructor, it is not the same. For example, a C++ destructor is always called just before an object goes out of scope, but you can’t know when finalize( ) will be called for any specific object. Frankly, because of Java’s use of garbage collection, there is little need for a destructor.
**Project 4-2**  Demonstrate Finalization

Because garbage collection runs sporadically, in the background, it is not trivial to demonstrate the `finalize()` method. Recall that `finalize()` is called when an object is about to be recycled. As explained, objects are not necessarily recycled as soon as they are no longer needed. Instead, the garbage collector waits until it can perform its collection efficiently, usually when there are many unused objects. Thus, to demonstrate the `finalize()` method, you often need to create and destroy a large number of objects—and this is precisely what you will do in this project.

**Step by Step**

1. Create a new file called `Finalize.java`.

2. Create the `FDemo` class shown here:

   ```java
   class FDemo {
   int x;

   FDemo(int i) {
      x = i;
   }

   // called when object is recycled
   protected void finalize() {
      System.out.println("Finalizing " + x);
   }

   // generates an object that is immediately destroyed
   void generator(int i) {
      FDemo o = new FDemo(i);
   }
   }
   
   The constructor sets the instance variable `x` to a known value. In this example, `x` is used as an object ID. The `finalize()` method displays the value of `x` when an object is recycled. Of special interest is `generator()`. This method creates and then promptly destroys an `FDemo` object. You will see how this is used in the next step.

   (continued)```
3. Create the **Finalize** class, shown here:

```java
class Finalize {
    public static void main(String args[]) {
        int count;

        FDemo ob = new FDemo(0);

        /* Now, generate a large number of objects. At some point, garbage collection will occur.
         * Note: you might need to increase the number of objects generated in order to force garbage collection. */

        for(count=1; count < 100000; count++)
            ob.generator(count);
    }
}
```

This class creates an initial **FDemo** object called ob. Then, using ob, it creates 100,000 objects by calling `generator()` on ob. This has the net effect of creating and destroying 100,000 objects. At various points in the middle of this process, garbage collection will take place. Precisely how often or when depends upon several factors, such as the initial amount of free memory and the operating system. However, at some point, you will start to see the messages generated by `finalize()`. If you don’t see the messages, try increasing the number of objects being generated by raising the count in the `for` loop.

4. Here is the entire **Finalize.java** program:

```java
/*
 * Project 4-2
 * Demonstrate the finalize() method.
 */

class FDemo {
    int x;

    FDemo(int i) {
        x = i;
    }

    // called when object is recycled
    protected void finalize() {
        System.out.println("Finalizing " + x);
    }
```
void generator(int i) {
    FDemo o = new FDemo(i);
}

class Finalize {
    public static void main(String args[]) {
        int count;

        FDemo ob = new FDemo(0);

        /* Now, generate a large number of objects. At
         * some point, garbage collection will occur.
         * Note: you might need to increase the number
         * of objects generated in order to force
         * garbage collection. */

        for(count=1; count < 100000; count++)
            ob.generator(count);
    }
}

CRITICAL SKILL

4.12 The this Keyword

Before concluding this module it is necessary to introduce this. When a method is called, it is
automatically passed an implicit argument that is a reference to the invoking object (that is, the
object on which the method is called). This reference is called this. To understand this, first
consider a program that creates a class called Pwr that computes the result of a number raised
to some integer power:

class Pwr {
    double b;
    int e;
    double val;

    Pwr(double base, int exp) {
        b = base;
        e = exp;

        val = 1;
        if(exp==0) return;
        for( ; exp>0; exp--) val = val * base;
class DemoPwr {
    public static void main(String args[]) {
        Pwr x = new Pwr(4.0, 2);
        Pwr y = new Pwr(2.5, 1);
        Pwr z = new Pwr(5.7, 0);

        System.out.println(x.b + " raised to the " + x.e + " power is " + x.get_pwr());
        System.out.println(y.b + " raised to the " + y.e + " power is " + y.get_pwr());
        System.out.println(z.b + " raised to the " + z.e + " power is " + z.get_pwr());
    }
}

As you know, within a method, the other members of a class can be accessed directly, without any object or class qualification. Thus, inside get_pwr(), the statement

    return val;

means that the copy of val associated with the invoking object will be returned. However, the same statement can also be written like this:

    return this.val;

Here, this refers to the object on which get_pwr() was called. Thus, this.val refers to that object’s copy of val. For example, if get_pwr() had been invoked on x, then this in the preceding statement would have been referring to x. Writing the statement without using this is really just shorthand.

Here is the entire Pwr class written using the this reference:

class Pwr {
    double b;
    int e;
    double val;

    Pwr(double base, int exp) {
        this.b = base;
    }
this.e = exp;
this.val = 1;
if(exp==0) return;
for( ; exp>0; exp--) this.val = this.val * base;
}

double get_pwr() {
    return this.val;
}
}

Actually, no Java programmer would write Pwr as just shown because nothing is gained, and the standard form is easier. However, this has some important uses. For example, the Java syntax permits the name of a parameter or a local variable to be the same as the name of an instance variable. When this happens, the local name hides the instance variable. You can gain access to the hidden instance variable by referring to it through this. For example, although not recommended style, the following is a syntactically valid way to write the Pwr( ) constructor.

Pwr(double b, int e) {
    this.b = b;
    this.e = e;
    val = 1;
    if(e==0) return;
    for( ; e>0; e--) val = val * b;
}

In this version, the names of the parameters are the same as the names of the instance variables, thus hiding them. However, this is used to “uncover” the instance variables.

\section*{Module 4 Mastery Check}

\begin{enumerate}
\item What is the difference between a class and an object?
\item How is a class defined?
\item What does each object have its own copy of?
\item Using two separate statements, show how to declare an object called counter of a class called MyCounter.
\end{enumerate}
5. Show how a method called `myMeth( )` is declared if it has a return type of `double` and has two `int` parameters called `a` and `b`.

6. How must a method return if it returns a value?

7. What name does a constructor have?

8. What does `new` do?

9. What is garbage collection, and how does it work? What is `finalize( )`?

10. What is `this`?

11. Can a constructor have one or more parameters?

12. If a method returns no value, what must its return type be?
Module 5
More Data Types and Operators

CRITICAL SKILLS

5.1 Understand and create arrays
5.2 Create multidimensional arrays
5.3 Create irregular arrays
5.4 Know the alternative array declaration syntax
5.5 Assign array references
5.6 Use the length array member
5.7 Work with strings
5.8 Apply command-line arguments
5.9 Use the bitwise operators
5.10 Apply the ? operator
This module returns to the subject of Java’s data types and operators. It discusses arrays, the `String` type, the bitwise operators, and the `?` ternary operator. Along the way, command-line arguments are described.

**Critical Skill 5.1 Arrays**

An array is a collection of variables of the same type, referred to by a common name. In Java, arrays can have one or more dimensions, although the one-dimensional array is the most common. Arrays are used for a variety of purposes because they offer a convenient means of grouping together related variables. For example, you might use an array to hold a record of the daily high temperature for a month, a list of stock price averages, or a list of your collection of programming books.

The principal advantage of an array is that it organizes data in such a way that it can be easily manipulated. For example, if you have an array containing the incomes for a selected group of households, it is easy to compute the average income by cycling through the array. Also, arrays organize data in such a way that it can be easily sorted.

Although arrays in Java can be used just like arrays in other programming languages, they have one special attribute: they are implemented as objects. This fact is one reason that a discussion of arrays was deferred until objects had been introduced. By implementing arrays as objects, several important advantages are gained, not the least of which is that unused arrays can be garbage collected.

**One-Dimensional Arrays**

A one-dimensional array is a list of related variables. Such lists are common in programming. For example, you might use a one-dimensional array to store the account numbers of the active users on a network. Another array might be used to store the current batting averages for a baseball team.

To declare a one-dimensional array, you will use this general form:

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

Here, `type` declares the base type of the array. The base type determines the data type of each element contained in the array. The number of elements that the array will hold is determined by `size`. Since arrays are implemented as objects, the creation of an array is a two-step process. First, you declare an array reference variable. Second, you allocate memory for the array, assigning a reference to that memory to the array variable. Thus, all arrays in Java are dynamically allocated using the `new` operator.
Here is an example. The following creates an `int` array of 10 elements and links it to an array reference variable named `sample`.

```java
int sample[] = new int[10];
```

This declaration works just like an object declaration. The `sample` variable holds a reference to the memory allocated by `new`. This memory is large enough to hold 10 elements of type `int`.

As with objects, it is possible to break the preceding declaration in two. For example:

```java
int sample[];
sample = new int[10];
```

In this case, when `sample` is first created, it is `null`, because it refers to no physical object. It is only after the second statement executes that `sample` is linked with an array.

An individual element within an array is accessed by use of an index. An index describes the position of an element within an array. In Java, all arrays have zero as the index of their first element. Because `sample` has 10 elements, it has index values of 0 through 9. To index an array, specify the number of the element you want, surrounded by square brackets. Thus, the first element in `sample` is `sample[0]`, and the last element is `sample[9]`. For example, the following program loads `sample` with the numbers 0 through 9.

```java
// Demonstrate a one-dimensional array.
class ArrayDemo {
    public static void main(String args[]) {
        int sample[] = new int[10];
        int i;

        for(i = 0; i < 10; i = i+1)
            sample[i] = i;

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

The output from the program is shown here:

```
This is sample[0]: 0
This is sample[1]: 1
This is sample[2]: 2
This is sample[3]: 3
```
This is sample[4]: 4
This is sample[5]: 5
This is sample[6]: 6
This is sample[7]: 7
This is sample[8]: 8
This is sample[9]: 9

Conceptually, the sample array looks like this:

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
</table>

Arrays are common in programming because they let you deal easily with large numbers of related variables. For example, the following program finds the minimum and maximum values stored in the nums array by cycling through the array using a for loop.

```java
// Find the minimum and maximum values in an array.
class MinMax {
    public static void main(String[] args) {
        int nums[] = new int[10];
        int min, max;

        nums[0] = 99;
        nums[1] = -10;
        nums[2] = 100123;
        nums[3] = 18;
        nums[4] = -978;
        nums[5] = 5623;
        nums[6] = 463;
        nums[7] = -9;
        nums[8] = 287;
        nums[9] = 49;

        min = max = nums[0];
        for(int i=1; i < 10; i++) {
            if(nums[i] < min) min = nums[i];
            if(nums[i] > max) max = nums[i];
        }
        System.out.println("min and max: " + min + " " + max);
    }
}
```
The output from the program is shown here:

min and max: -978 100123

In the preceding program, the `nums` array was given values by hand, using 10 separate assignment statements. Although perfectly correct, there is an easier way to accomplish this. Arrays can be initialized when they are created. The general form for initializing a one-dimensional array is shown here:

```java
type array-name[] = { val1, val2, val3, ..., valN };
```

Here, the initial values are specified by `val1` through `valN`. They are assigned in sequence, left to right, in index order. Java automatically allocates an array large enough to hold the initializers that you specify. There is no need to explicitly use the `new` operator. For example, here is a better way to write the `MinMax` program:

```java
// Use array initializers.
class MinMax2 {
    public static void main(String args[]) {
        int nums[] = {99, -10, 100123, 18, -978, 5623, 463, -9, 287, 49};
        int min, max;
        min = max = nums[0];
        for(int i=1; i < 10; i++) {
            if(nums[i] < min) min = nums[i];
            if(nums[i] > max) max = nums[i];
        }
        System.out.println("Min and max: "+min+" "+max);
    }
}
```

Array boundaries are strictly enforced in Java; it is a run-time error to overrun or underrun the end of an array. If you want to confirm this for yourself, try the following program that purposely overruns an array.

```java
// Demonstrate an array overrun.
class ArrayErr {
    public static void main(String args[]) {
        int sample[] = new int[10];
        int i;

        // generate an array overrun
        for(i = 0; i < 100; i = i+1)
            sample[i] = i;
    }
}
```
As soon as i reaches 10, an ArrayIndexOutOfBoundsException is generated and the program is terminated.

Progress Check

1. Arrays are accessed via an _______.
2. How is a 10-element char array declared?
3. Java does not check for array overruns at run time. True or False?

Project 5-1 Sorting an Array

Because a one-dimensional array organizes data into an indexable linear list, it is the perfect data structure for sorting. In this project you will learn a simple way to sort an array. As you may know, there are a number of different sorting algorithms. There are the quick sort, the shaker sort, and the shell sort, to name just three. However, the best known, simplest, and easiest to understand is called the Bubble sort. Although the Bubble sort is not very efficient—in fact, its performance is unacceptable for sorting large arrays—it may be used effectively for sorting small arrays.

Step by Step

1. Create a file called Bubble.java.

2. The Bubble sort gets its name from the way it performs the sorting operation. It uses the repeated comparison and, if necessary, exchange of adjacent elements in the array. In this process, small values move toward one end and large ones toward the other end. The process is conceptually similar to bubbles finding their own level in a tank of water. The Bubble sort operates by making several passes through the array, exchanging out-of-place elements

1. index
2. char a[] = new char[10];
3. False. Java does not allow array overruns at run time.
when necessary. The number of passes required to ensure that the array is sorted is equal to
one less than the number of elements in the array.

Here is the code that forms the core of the Bubble sort. The array being sorted is
called `nums`.

```java
// This is the Bubble sort.
for(a=1; a < size; a++)
    for(b=size-1; b >= a; b--) {
        if(nums[b-1] > nums[b]) { // if out of order
            // exchange elements
            t = nums[b-1];
            nums[b-1] = nums[b];
            nums[b] = t;
        }
    }
```

Notice that sort relies on two `for` loops. The inner loop checks adjacent elements in the
array, looking for out-of-order elements. When an out-of-order element pair is found,
the two elements are exchanged. With each pass, the smallest of the remaining elements
moves into its proper location. The outer loop causes this process to repeat until the entire
array has been sorted.

3. Here is the entire `Bubble` program:

```java
/*
   Project 5-1

   Demonstrate the Bubble sort.
*/

class Bubble {
    public static void main(String args[]) {
        int nums[] = { 99, -10, 100123, 18, -978,
                      5623, 463, -9, 287, 49 };
        int a, b, t;
        int size;

        size = 10; // number of elements to sort

        // display original array
        System.out.print("Original array is:");
        for(int i=0; i < size; i++)
```

(continued)
System.out.print(" " + nums[i]);
System.out.println();

// This is the Bubble sort.
for(a=1; a < size; a++)
   for(b=size-1; b >= a; b--) {
      if(nums[b-1] > nums[b]) { // if out of order
         // exchange elements
            t = nums[b-1];
            nums[b-1] = nums[b];
            nums[b] = t;
      }
   }

// display sorted array
System.out.print("Sorted array is:");
for(int i=0; i < size; i++)
   System.out.print(" " + nums[i]);
System.out.println();
}
}

The output from the program is shown here:

Original array is: 99 -10 100123 18 -978 5623 463 -9 287 49
Sorted array is: -978 -10 -9 18 49 99 287 463 5623 100123

4. Although the Bubble sort is good for small arrays, it is not efficient when used on larger ones. The best general-purpose sorting algorithm is the quick sort. The quick sort, however, relies on features of Java that you have not yet learned about.

CRITICAL SKILL

5.2 Multidimensional Arrays

Although the one-dimensional array is the most commonly used array in programming, multidimensional arrays (arrays of two or more dimensions) are certainly not rare. In Java, a multidimensional array is an array of arrays.

Two-Dimensional Arrays

The simplest form of the multidimensional array is the two-dimensional array. A two-dimensional array is, in essence, a list of one-dimensional arrays. To declare a two-dimensional integer array table of size 10, 20 you would write

int table[][] = new int[10][20];
Pay careful attention to the declaration. Unlike some other computer languages, which use commas to separate the array dimensions, Java places each dimension in its own set of brackets. Similarly, to access point 3, 5 of array `table`, you would use `table[3][5].`

In the next example, a two-dimensional array is loaded with the numbers 1 through 12.

```java
// Demonstrate a two-dimensional array.
class TwoD {
    public static void main(String args[]) {
        int t, i;
        int table[][] = new int[3][4];

        for(t=0; t < 3; ++t) {
            for(i=0; i < 4; ++i) {
                table[t][i] = (t*4)+i+1;
                System.out.print(table[t][i] + " ");
            }
            System.out.println();
        }
    }
}
```

In this example, `table[0][0]` will have the value 1, `table[0][1]` the value 2, `table[0][2]` the value 3, and so on. The value of `table[2][3]` will be 12. Conceptually, the array will look like that shown in Figure 5-1.

![Conceptual view of the table array created by the TwoD program](image_url)

**Figure 5-1** Conceptual view of the table array created by the TwoD program
Irregular Arrays

When you allocate memory for a multidimensional array, you need to specify only the memory for the first (leftmost) dimension. You can allocate the remaining dimensions separately. For example, the following code allocates memory for the first dimension of `table` when it is declared. It allocates the second dimension manually.

```java
int table[][] = new int[3][];
table[0] = new int[4];
table[1] = new int[4];
table[2] = new int[4];
```

Although 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 manually, you do not need to allocate the same number of elements for each dimension. Since multidimensional arrays are implemented as arrays of arrays, the length of each array is under your control. For example, assume you are writing a program that stores the number of passengers that ride an airport shuttle. If the shuttle runs 10 times a day during the week and twice a day on Saturday and Sunday, you could use the `riders` array shown in the following program to store the information. Notice that the length of the second dimension for the first five dimensions is 10 and the length of the second dimension for the last two dimensions is 2.

```java
// Manually allocate differing size second dimensions.
class Ragged {
    public static void main(String args[]) {
        int riders[][] = new int[7][];
        riders[0] = new int[10];
        riders[1] = new int[10];
        riders[2] = new int[10];
        riders[3] = new int[10];
        riders[4] = new int[10];
        riders[5] = new int[2];
        riders[6] = new int[2];

        int i, j;

        // fabricate some fake data
        for(i=0; i < 5; i++)
            for(j=0; j < 10; j++)
                riders[i][j] = i + j + 10;
        for(i=5; i < 7; i++)
            for(j=0; j < 2; j++)
```
riders[i][j] = i + j + 10;

System.out.println("Riders per trip during the week:");
for(i=0; i < 5; i++) {
    for(j=0; j < 10; j++)
        System.out.print(riders[i][j] + " ");
    System.out.println();
}
System.out.println();

System.out.println("Riders per trip on the weekend:");
for(i=5; i < 7; i++) {
    for(j=0; j < 2; j++)
        System.out.print(riders[i][j] + " ");
    System.out.println();
}

The use of irregular (or ragged) multidimensional arrays is not recommended for most 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), an irregular array might be a perfect solution.

Arrays of Three or More Dimensions
Java allows arrays with more than two dimensions. Here is the general form of a multidimensional array declaration:

type name[ ] [ ] [ ] = new type[size1][size2][sizeN];

For example, the following declaration creates a 4 x 10 x 3 three-dimensional integer array.

int multidim[][][] = new int[4][10][3];

Initializing Multidimensional Arrays
A multidimensional array can be initialized by enclosing each dimension’s initializer list within its own set of curly braces. For example, the general form of array initialization for a two-dimensional array is shown here:

type-specifier array_name[ ] [ ] = {
    { val, val, val, ..., val },
    { val, val, val, ..., val },
}
Here, \textit{val} indicates an initialization value. Each inner block designates a row. Within each row, the first value will be stored in the first position of the array, the second value in the second position, and so on. Notice that commas separate the initializer blocks and that a semicolon follows the closing \{.

For example, the following program initializes an array called \texttt{sqrs} with the numbers 1 through 10 and their squares.

\begin{verbatim}
// Initialize a two-dimensional array.
class Squares {
   public static void main(String args[]) {
      int sqrs[][] = {
         { 1, 1 },
         { 2, 4 },
         { 3, 9 },
         { 4, 16 },
         { 5, 25 },
         { 6, 36 },
         { 7, 49 },
         { 8, 64 },
         { 9, 81 },
         { 10, 100 }
      };
      int i, j;

      for(i=0; i < 10; i++) {
         for(j=0; j < 2; j++)
            System.out.print(sqrs[i][j] + " ");
      System.out.println();
   }
}
\end{verbatim}

Here is the output from the program:

\begin{verbatim}
 1 1
 2 4
 3 9
 4 16
 5 25
 6 36
\end{verbatim}
Progress Check

1. For multidimensional arrays, each dimension is specified how?
2. In a two-dimensional array, which is an array of arrays, can the length of each array differ?
3. How are multidimensional arrays initialized?

CRITICAL SKILL

Alternative Array Declaration Syntax

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

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

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

```java
int counter[] = new int[3];
int[] counter = new int[3];
```

The following declarations are also equivalent:

```java
char table[][] = new char[3][4];
char[][] table = new char[3][4];
```

This alternative declaration form is used by many Java programmers, and you should become familiar with it.

1. Each dimension is specified within its own set of square brackets.
2. Yes.
3. Multidimensional arrays are initialized by putting each subarray’s initializers inside their own set of curly braces.
Assigning Array References

Like other objects, when you assign one array reference variable to another, you are simply changing what object that variable refers to. You are not causing a copy of the array to be made, nor are you causing the contents of one array to be copied to the other. For example, consider this program:

```java
// Assigning array reference variables.
class AssignArrayRef {
    public static void main(String args[]) {
        int i;

        int nums1[] = new int[10];
        int nums2[] = new int[10];

        for(i=0; i < 10; i++)
            nums1[i] = i;

        for(i=0; i < 10; i++)
            nums2[i] = -i;

        System.out.print("Here is nums1: ");
        for(i=0; i < 10; i++)
            System.out.print(nums1[i] + " ");
        System.out.println();

        System.out.print("Here is nums2: ");
        for(i=0; i < 10; i++)
            System.out.print(nums2[i] + " ");
        System.out.println();

        nums2 = nums1; // now nums2 refers to nums1

        System.out.print("Here is nums2 after assignment: ");
        for(i=0; i < 10; i++)
            System.out.print(nums2[i] + " ");
        System.out.println();

        // now operate on nums1 array through nums2
        nums2[3] = 99;

        System.out.print("Here is nums1 after change through nums2: ");
    }
}
```
```java
for(i=0; i < 10; i++)
    System.out.print(nums1[i] + " ");
System.out.println();
}
}
```

The output from the program is shown here:

Here is nums1: 0 1 2 3 4 5 6 7 8 9
Here is nums2: 0 -1 -2 -3 -4 -5 -6 -7 -8 -9
Here is nums2 after assignment: 0 1 2 3 4 5 6 7 8 9
Here is nums1 after change through nums2: 0 1 2 99 4 5 6 7 8 9

As the output shows, after the assignment of `nums1` to `nums2`, both array reference variables refer to the same object.

### Using the length Member

Because arrays are implemented as objects, each array has associated with it a **length** instance variable that contains the number of elements that the array can hold. Here is a program that demonstrates this property:

```java
// Use the length array member.
class LengthDemo {
    public static void main(String args[]) {
        int list[] = new int[10];
        int nums[] = { 1, 2, 3 };
        int table[][] = { // a variable-length table
            { 1, 2, 3 },
            { 4, 5 },
            { 6, 7, 8, 9 }
        };

        System.out.println("length of list is " + list.length);
        System.out.println("length of nums is " + nums.length);
        System.out.println("length of table is " + table.length);
        System.out.println("length of table[0] is " + table[0].length);
        System.out.println("length of table[1] is " + table[1].length);
        System.out.println("length of table[2] is " + table[2].length);
        System.out.println();
    }
}
```
// use length to initialize list
for(int i=0; i < list.length; i++)
    list[i] = i * i;

System.out.print("Here is list: ");
// now use length to display list
for(int i=0; i < list.length; i++)
    System.out.print(list[i] + " ");
System.out.println();
}
}

This program displays the following output:

length of list is 10
length of nums is 3
length of table is 3
length of table[0] is 3
length of table[1] is 2
length of table[2] is 4

Here is list: 0 1 4 9 16 25 36 49 64 81

Pay special attention to the way length is used with the two-dimensional array table. As explained, a two-dimensional array is an array of arrays. Thus, when the expression

table.length

is used, it obtains the number of arrays stored in table, which is 3 in this case. To obtain the length of any individual array in table, you will use an expression such as this,

table[0].length

which, in this case, obtains the length of the first array.

One other thing to notice in LengthDemo is the way that list.length is used by the for loops to govern the number of iterations that take place. Since each array carries with it its own length, you can use this information rather than manually keeping track of an array’s size. Keep in mind that the value of length has nothing to do with the number of elements that are actually in use. It contains the number of elements that the array is capable of holding.

The inclusion of the length member simplifies many algorithms by making certain types of array operations easier—and safer—to perform. For example, the following program uses length to copy one array to another while preventing an array overrun and its attendant run-time exception.
// Use length variable to help copy an array.
class ACopy {
    public static void main(String args[]) {
        int i;
        int nums1[] = new int[10];
        int nums2[] = new int[10];

        for(i=0; i < nums1.length; i++)
            nums1[i] = i;

        // copy nums1 to nums2
        if(nums2.length >= nums1.length)
            for(i = 0; i < nums2.length; i++)
                nums2[i] = nums1[i];

        for(i=0; i < nums2.length; i++)
            System.out.print(nums2[i] + " ");
    }
}

Here, length helps perform two important functions. First, it is used to confirm that the target array is large enough to hold the contents of the source array. Second, it provides the termination condition of the for loop that performs the copy. Of course, in this simple example, the sizes of the arrays are easily known, but this same approach can be applied to a wide range of more challenging situations.

Progress Check

1. How can the following be rewritten?
   
   ```java
   int x[] = new int[10];
   ```

2. When one array reference is assigned to another, the elements of the first array are copied to the second. True or False?

3. As it pertains to arrays, what is length?

1. int[] x = new int[10]
2. False. Only the reference is changed.
3. length is an instance variable that all arrays have. It contains the number of elements that the array can hold.
Project 5-2 A Queue Class

As you may know, a data structure is a means of organizing data. The simplest data structure is the array, which is a linear list that supports random access to its elements. Arrays are often used as the underpinning for more sophisticated data structures, such as stacks and queues. A stack is a list in which elements can be accessed in first-in, last-out (FILO) order only. A queue is a list in which elements can be accessed in first-in, first-out (FIFO) order only. Thus, a stack is like a stack of plates on a table—the first down is the last to be used. A queue is like a line at a bank—the first in line is the first served.

What makes data structures such as stacks and queues interesting is that they combine storage for information with the methods that access that information. Thus, stacks and queues are data engines in which storage and retrieval are provided by the data structure itself, not manually by your program. Such a combination is, obviously, an excellent choice for a class, and in this project you will create a simple queue class.

In general, queues support two basic operations: put and get. Each put operation places a new element on the end of the queue. Each get operation retrieves the next element from the front of the queue. Queue operations are consumptive: once an element has been retrieved, it cannot be retrieved again. The queue can also become full, if there is no space available to store an item, and it can become empty, if all of the elements have been removed.

One last point: there are two basic types of queues—circular and noncircular. A circular queue reuses locations in the underlying array when elements are removed. A noncircular queue does not reuse locations and eventually becomes exhausted. For the sake of simplicity, this example creates a noncircular queue, but with a little thought and effort, you can easily transform it into a circular queue.

Step by Step

1. Create a file called QDemo.java.

2. Although there are other ways to support a queue, the method we will use is based upon an array. That is, an array will provide the storage for the items put into the queue. This array will be accessed through two indices. The put index determines where the next element of data will be stored. The get index indicates at what location the next element of data will be obtained. Keep in mind that the get operation is consumptive, and it is not possible to retrieve the same element twice. Although the queue that we will be creating stores characters, the same logic can be used to store any type of object. Begin creating the Queue class with these lines:

   ```java
   class Queue {
       char q[]; // this array holds the queue
       int putloc, getloc; // the put and get indices
   }
   ```
3. The constructor for the **Queue** class creates a queue of a given size. Here is the **Queue** constructor:

```java
Queue(int size) {
    q = new char[size+1]; // allocate memory for queue
    putloc = getloc = 0;
}
```

Notice that the queue is created one larger than the size specified in `size`. Because of the way the queue algorithm will be implemented, one array location will be unused, so the array must be created one larger than the requested queue size. The put and get indices are initially set to zero.

4. The **put( )** method, which stores elements, is shown next:

```java
// put a character into the queue
void put(char ch) {
    if(putloc==q.length-1) {
        System.out.println(" -- Queue is full.");
        return;
    }
    putloc++;
    q[putloc] = ch;
}
```

The method begins by checking for a queue-full condition. If `putloc` is equal to the last location in the `q` array, there is no more room in which to store elements. Otherwise, `putloc` is incremented and the new element is stored at that location. Thus, `putloc` is always the index of the last element stored.

5. To retrieve elements, use the **get( )** method, shown next:

```java
// get a character from the queue
char get() { 
    if(getloc == putloc) {
        System.out.println(" -- Queue is empty.");
        return (char) 0;
    }
    getloc++;
    return q[getloc];
}
```

Notice first the check for queue-empty. If `getloc` and `putloc` both index the same element, the queue is assumed to be empty. This is why `getloc` and `putloc` were both initialized to zero by the **Queue** constructor. Next, `getloc` is incremented and the next element is returned. Thus, `getloc` always indicates the location of the last element retrieved.

(continued)
6. Here is the entire `QDemo.java` program:

```java
/*
   Project 5-2

   A queue class for characters.
*/

class Queue {
    char q[]; // this array holds the queue
    int putloc, getloc; // the put and get indices

    Queue(int size) {
        q = new char[size+1]; // allocate memory for queue
        putloc = getloc = 0;
    }

    // put a character into the queue
    void put(char ch) {
        if(putloc==q.length-1) {
            System.out.println(" -- Queue is full.");
            return;
        }

        putloc++;
        q[putloc] = ch;
    }

    // get a character from the queue
    char get() {
        if(getloc == putloc) {
            System.out.println(" -- Queue is empty.");
            return (char) 0;
        }

        getloc++;
        return q[getloc];
    }
}

// Demonstrate the Queue class.
class QDemo {
    public static void main(String args[]) {
        Queue bigQ = new Queue(100);
        Queue smallQ = new Queue(4);
    }
}
```
char ch;
int i;

System.out.println("Using bigQ to store the alphabet.");
// put some numbers into bigQ
for(i=0; i < 26; i++)
    bigQ.put((char) ('A' + i));

// retrieve and display elements from bigQ
System.out.print("Contents of bigQ: ");
for(i=0; i < 26; i++) {
    ch = bigQ.get();
    if(ch != (char) 0) System.out.print(ch);
}

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

System.out.println("Using smallQ to generate errors.");
// Now, use smallQ to generate some errors
for(i=0; i < 5; i++) {
    System.out.print("Attempting to store " +
                     (char) ('Z' - i));
    smallQ.put((char) ('Z' - i));

    System.out.println();
}
System.out.println();

// more errors on smallQ
System.out.print("Contents of smallQ: ");
for(i=0; i < 5; i++) {
    ch = smallQ.get();
    if(ch != (char) 0) System.out.print(ch);
}
}

7. The output produced by the program is shown here:

Using bigQ to store the alphabet.
Contents of bigQ: ABCDEFGHIJKLMNOPQRSTUVWXYZ

Using smallQ to generate errors.

(continued)
Attempting to store Z
Attempting to store Y
Attempting to store X
Attempting to store W
Attempting to store V -- Queue is full.

Contents of smallQ: ZYXW -- Queue is empty.

8. On your own, try modifying Queue so that it stores other types of objects. For example, have it store ints or doubles.

**Strings**

From a day-to-day programming standpoint, one of the most important of Java’s data types is **String**. **String** defines and supports character strings. In many other programming languages a string is an array of characters. This is not the case with Java. In Java, strings are objects.

Actually, you have been using the **String** class since Module 1, but you did not know it. When you create a string literal, you are actually creating a **String** object. For example, in the statement

```java
System.out.println("In Java, strings are objects.");
```

the string "In Java, strings are objects." is automatically made into a **String** object by Java. Thus, the use of the **String** class has been “below the surface” in the preceding programs. In the following sections you will learn to handle it explicitly. Be aware, however, that the **String** class is quite large, and we will only scratch its surface here. It is a class that you will want to explore on its own.

**Constructing Strings**

You can construct a **String** just like you construct any other type of object: by using **new** and calling the **String** constructor. For example:

```java
String str = new String("Hello");
```

This creates a **String** object called **str** that contains the character string "Hello". You can also construct a **String** from another **String**. For example:
String str = new String("Hello");
String str2 = new String(str);

After this sequence executes, str2 will also contain the character string "Hello".

Another easy way to create a String is shown here:

String str = "Java strings are powerful.";

In this case, str is initialized to the character sequence "Java strings are powerful."

Once you have created a String object, you can use it anywhere that a quoted string is allowed. For example, you can use a String object as an argument to println(), as shown in this example:

```java
// Introduce String.
class StringDemo {
    public static void main(String args[]) {
        // declare strings in various ways
        String str1 = new String("Java strings are objects.");
        String str2 = "They are constructed various ways."
        String str3 = new String(str2);

        System.out.println(str1);
        System.out.println(str2);
        System.out.println(str3);
    }
}
```

The output from the program is shown here:

Java strings are objects.
They are constructed various ways.
They are constructed various ways.

**Operating on Strings**

The String class contains several methods that operate on strings. Here are a few:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean equals(String str)</td>
<td>Returns true if the invoking string contains the same character sequence as str.</td>
</tr>
<tr>
<td>int length( )</td>
<td>Obtains the length of a string.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>char charAt(int index)</td>
<td>Obtains the character at the index specified by index.</td>
</tr>
<tr>
<td>int compareTo(String str)</td>
<td>Returns less than zero if the invoking string is less than str, greater than zero if the invoking string is greater than str, and zero if the strings are equal.</td>
</tr>
<tr>
<td>int indexOf(String str)</td>
<td>Searches the invoking string for the substring specified by str. Returns the index of the first match or $-1$ on failure.</td>
</tr>
<tr>
<td>int lastIndexOf(String str)</td>
<td>Searches the invoking string for the substring specified by str. Returns the index of the last match or $-1$ on failure.</td>
</tr>
</tbody>
</table>

Here is a program that demonstrates these methods:

```java
// Some String operations.
class StrOps {
    public static void main(String args[]) {
        String str1 =
            "When it comes to Web programming, Java is #1."
        ;
        String str2 = new String(str1);
        String str3 = "Java strings are powerful.";
        int result, idx;
        char ch;

        System.out.println("Length of str1: " +
            str1.length());

        // display str1, one char at a time.
        for(int i=0; i < str1.length(); i++)
            System.out.print(str1.charAt(i));
        System.out.println();

        if(str1.equals(str2))
            System.out.println("str1 == str2");
        else
            System.out.println("str1 != str2");

        if(str1.equals(str3))
            System.out.println("str1 == str3");
        else
            System.out.println("str1 != str3");

        result = str1.compareTo(str3);
        if(result == 0)
            System.out.println("str1 and str3 are equal");
        else if(result < 0)
            System.out.println("str1 is less than str3");
        else
```
```java
System.out.println("str1 is greater than str3");

// assign a new string to str2
str2 = "One Two Three One";

idx = str2.indexOf("One");
System.out.println("Index of first occurrence of One: " + idx);
idx = str2.lastIndexOf("One");
System.out.println("Index of last occurrence of One: " + idx);
}
}

This program generates the following output:

Length of str1: 45
When it comes to Web programming, Java is #1.
str1 == str2
str1 != str3
str1 is greater than str3
Index of first occurrence of One: 0
Index of last occurrence of One: 14

You can concatenate (join together) two strings using the + operator. For example, this statement

String str1 = "One";
String str2 = "Two";
String str3 = "Three";
String str4 = str1 + str2 + str3;

initializes str4 with the string "OneTwoThree".

Ask the Expert

Q: Why does String define the equals() method? Can’t I just use ==?

A: The equals() method compares the character sequences of two String objects for equality. Applying the == to two String references simply determines whether the two references refer to the same object.
Arrays of Strings

Like any other data type, strings can be assembled into arrays. For example:

```java
// Demonstrate String arrays.
class StringArrays {
    public static void main(String args[]) {
        String str[] = {"This", "is", "a", "test."};

        System.out.println("Original array: ");
        for(int i=0; i < str.length; i++)
            System.out.print(str[i] + " ");
        System.out.println("\n");

        // change a string
        str[1] = "was";
        str[3] = "test, too!";

        System.out.println("Modified array: ");
        for(int i=0; i < str.length; i++)
            System.out.print(str[i] + " ");
    }
}
```

Here is the output from this program:

Original array:  
This is a test.

Modified array:  
This was a test, too!

Strings Are Immutable

The contents of a `String` object are immutable. That is, once created, the character sequence that makes up the string cannot be altered. This restriction allows Java to implement strings more efficiently. Even though this probably sounds like a serious drawback, it isn’t. When you need a string that is a variation on one that already exists, simply create a new string that contains the desired changes. Since unused `String` objects are automatically garbage collected, you don’t even need to worry about what happens to the discarded strings.

It must be made clear, however, that `String` reference variables may, of course, change the object to which they refer. It is just that the contents of a specific `String` object cannot be changed after it is created.

To fully understand why immutable strings are not a hindrance, we will use another of `String`’s methods: `substring()`. The `substring()` method returns a new string that contains a
specified portion of the invoking string. Because a new `String` object is manufactured that contains the substring, the original string is unaltered, and the rule of immutability remains intact. The form of `substring()` that we will be using is shown here:

```
String substring(int startIndex, int endIndex)
```

Here, `startIndex` specifies the beginning index, and `endIndex` specifies the stopping point.

Here is a program that demonstrates `substring()` and the principle of immutable strings:

```java
// Use substring().
class SubStr {
    public static void main(String args[]) {
        String orgstr = "Java makes the Web move.";

        // construct a substring
        String substr = orgstr.substring(5, 18);

        System.out.println("orgstr: "+ orgstr);
        System.out.println("substr: "+ substr);
    }
}
```

Here is the output from the program:

```
orgstr: Java makes the Web move.
substr: makes the Web
```

As you can see, the original string `orgstr` is unchanged, and `substr` contains the substring.

**Ask the Expert**

**Q:** You say that once created, `String` objects are immutable. I understand that, from a practical point of view, this is not a serious restriction, but what if I want to create a string that can be changed?

**A:** You’re in luck. Java offers a class called `StringBuffer`, which creates string objects that can be changed. For example, in addition to the `charAt()` method, which obtains the character at a specific location, `StringBuffer` defines `setCharAt()`, which sets a character within the string. However, for most purposes you will want to use `String`, not `StringBuffer`. 
Using Command-Line Arguments

Now that you know about the String class, you can understand the args parameter to main() that has been in every program shown so far. Many programs accept what are called command-line arguments. 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 the String array passed to main(). For example, the following program displays all of the command-line arguments that it is called with:

```java
// Display all command-line information.
class CLDemo {
    public static void main(String args[]) {
        System.out.println("There are " + args.length + " command-line arguments.");
        System.out.println("They are: ");
        for(int i=0; i<args.length; i++)
            System.out.println(args[i]);
    }
}
```

If CLDemo is executed like this,

```
java CLDemo one two three
```

you will see the following output:

There are 3 command-line arguments.
They are:
one	
two	
three	

To get a taste of the way command-line arguments can be used, consider the next program. It takes one command-line argument that specifies a person’s name. It then searches through a two-dimensional array of strings for that name. If it finds a match, it displays that person’s telephone number.

```java
// A simple automated telephone directory.
class Phone {
    public static void main(String args[]) {
```
String numbers[][] = {
    { "Tom", "555-3322" },
    { "Mary", "555-8976" },
    { "Jon", "555-1037" },
    { "Rachel", "555-1400" }
};
int i;

if(args.length != 1)
    System.out.println("Usage: java Phone <name> ");
else {
    for(i=0; i<numbers.length; i++) {
        if(numbers[i][0].equals(args[0])) {
            System.out.println(numbers[i][0] + ": " +
                             numbers[i][1]);
            break;
        }
    }
    if(i == numbers.length)
        System.out.println("Name not found.");
}

Here is a sample run:

C>java Phone Mary
Mary: 555-8976

Progress Check

1. In Java, all strings are objects. True or False?

2. How can you obtain the length of a string?

3. What are command-line arguments?

1. True.
2. The length of a string can be obtained by calling the length() method.
3. Command-line arguments are specified on the command line when a program is executed. They are passed as strings to the args parameter of main().
The Bitwise Operators

In Module 2 you learned about Java’s arithmetic, relational, and logical operators. Although these are the most commonly used, Java provides additional operators that expand the set of problems to which Java can be applied: the bitwise operators. The bitwise operators act directly upon the bits within the integer types, long, int, short, char, and byte. Bitwise operations cannot be used on boolean, float, or double, or class types. They are called the bitwise operators because they are used to test, set, or shift the bits that make up an integer value. Bitwise operations are important to a wide variety of systems-level programming tasks in which status information from a device must be interrogated or constructed. Table 5-1 lists the bitwise operators.

The Bitwise AND, OR, XOR, and NOT Operators

The bitwise operators AND, OR, XOR, and NOT are &, |, ^, and ~. They perform the same operations as their Boolean logic equivalents described in Module 2. The difference is that the bitwise operators work on a bit-by-bit basis. The following table shows the outcome of each operation using 1’s and 0’s.

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

<table>
<thead>
<tr>
<th>Operator</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;</td>
<td>Bitwise AND</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>^</td>
<td>Bitwise exclusive OR</td>
</tr>
<tr>
<td>&gt;&gt;</td>
<td>Shift right</td>
</tr>
<tr>
<td>&gt;&gt;&gt;</td>
<td>Unsigned shift right</td>
</tr>
<tr>
<td>&lt;&lt;</td>
<td>Shift left</td>
</tr>
<tr>
<td>~</td>
<td>One’s complement (unary NOT)</td>
</tr>
</tbody>
</table>

Table 5-1 The Bitwise Operators
In terms of its most common usage, you can think of the bitwise AND as a way to turn bits off. That is, any bit that is 0 in either operand will cause the corresponding bit in the outcome to be set to 0. For example:

\[
\begin{array}{cccccccc}
1 & 1 & 0 & 1 & 0 & 0 & 1 & 1 \\
\& & 1 & 0 & 1 & 0 & 1 & 0 \\
\end{array}
\]

1 0 0 0 0 0 1 0

The following program demonstrates the \& by turning any lowercase letter into uppercase by resetting the 6th bit to 0. As the Unicode/ASCII character set is defined, the lowercase letters are the same as the uppercase ones except that the lowercase ones are greater in value by exactly 32. Therefore, to transform a lowercase letter to uppercase, just turn off the 6th bit, as this program illustrates.

```java
// Uppercase letters.
class UpCase {
    public static void main(String args[]) {
        char ch;

        for(int i=0; i < 10; i++) {
            ch = (char) ('a' + i);
            System.out.print(ch);

            // This statement turns off the 6th bit.
            ch = (char) ((int) ch & 65503); // ch is now uppercase

            System.out.print(ch + " ");
        }
    }
}
```

The output from this program is shown here:

aA bB cC dD eE fF gG hH iI jJ

The value 65,503 used in the AND statement is the decimal representation of 1111 1111 1101 1111. Thus, the AND operation leaves all bits in \textit{ch} unchanged except for the 6th one, which is set to 0.

The AND operator is also useful when you want to determine whether a bit is on or off. For example, this statement determines whether bit 4 in \textit{status} is set:

```java
if(status & 8) System.out.println("bit 4 is on");
```
The number 8 is used because it translates into a binary value that has only the 4th bit set. Therefore, the if statement can succeed only when bit 4 of status is also on. An interesting use of this concept is to show the bits of a byte value in binary format.

```java
// Display the bits within a byte.
class ShowBits {
    public static void main(String args[]) {
        int t;
        byte val;

        val = 123;
        for(t=128; t > 0; t = t/2) {
            if((val & t) != 0) System.out.print("1 ");
            else System.out.print("0 ");
        }
    }
}
```

The output is shown here:

```
0 1 1 1 1 0 1 1
```

The for loop successively tests each bit in val, using the bitwise AND, to determine whether it is on or off. If the bit is on, the digit 1 is displayed; otherwise 0 is displayed. In Project 5-3, you will see how this basic concept can be expanded to create a class that will display the bits in any type of integer.

The bitwise OR, as the reverse of AND, can be used to turn bits on. Any bit that is set to 1 in either operand will cause the corresponding bit in the variable to be set to 1. For example:

```
1 1 0 1 0 0 1 1
| 1 0 1 0 1 0 1 0
1 1 1 1 1 0 1 1
```

We can make use of the OR to change the uppercasing program into a lowercasing program, as shown here:

```java
// Lowercase letters.
class LowCase {
    public static void main(String args[]) {
        char ch;

        for(int i=0; i < 10; i++) {
            ch = (char) ('A' + i);
            System.out.print(ch);
        }
    }
}
```
```java
// This statement turns on the 6th bit.
ch = (char) ((int) ch | 32); // ch is now lowercase
System.out.print(ch + " ");
}
}
}

The output from this program is shown here:
Aa Bb Cc Dd Ee Ff Gg Hh Ii Jj

The program works by ORing each character with the value 32, which is 0000 0000 0010 0000 in binary. Thus, 32 is the value that produces a value in binary in which only the 6th bit is set. When this value is ORed with any other value, it produces a result in which the 6th bit is set and all other bits remain unchanged. As explained, for characters this means that each uppercase letter is transformed into its lowercase equivalent.

An exclusive OR, usually abbreviated XOR, will set a bit on if, and only if, the bits being compared are different, as illustrated here:

```
0 1 1 1 1 1 1 1
^ 1 0 1 1 1 0 0 1
1 1 0 0 0 1 1 0
```

The XOR operator has an interesting property that makes it a simple way to encode a message. When some value X is XORed with another value Y, and then that result is XORed with Y again, X is produced. That is, given the sequence

```
R1 = X ^ Y;
R2 = R1 ^ Y;
```

then R2 is the same value as X. Thus, the outcome of a sequence of two XORs using the same value produces the original value.

You can use this principle to create a simple cipher program in which some integer is the key that is used to both encode and decode a message by XORing the characters in that message. To encode, the XOR operation is applied the first time, yielding the cipher text. To decode, the XOR is applied a second time, yielding the plain text. Here is a simple example that uses this approach to encode and decode a short message:

```java
// Use XOR to encode and decode a message.
class Encode {
    public static void main(String args[]) {
        String msg = "This is a test";
        String encmsg = "";
        String decmsg = "";
        int key = 88;
```

System.out.print("Original message: ");
System.out.println(msg);

// encode the message
for(int i=0; i < msg.length(); i++)
    encmsg = encmsg + (char) (msg.charAt(i) ^ key);
System.out.print("Encoded message: ");
System.out.println(encmsg);

// decode the message
for(int i=0; i < msg.length(); i++)
    decmsg = decmsg + (char) (encmsg.charAt(i) ^ key);
System.out.print("Decoded message: ");
System.out.println(decmsg);
}

Here is the output:

Original message: This is a test
Encoded message: 01+x1+x9x,=+,
Decoded message: This is a test

As you can see, the result of two XORs using the same key produces the decoded message.

The unary one’s complement (NOT) operator reverses the state of all the bits of the operand. For example, if some integer called \(A\) has the bit pattern 1001 0110, then \(\sim A\) produces a result with the bit pattern 0110 1001.

The following program demonstrates the NOT operator by displaying a number and its complement in binary.

// Demonstrate the bitwise NOT.
class NotDemo {
    public static void main(String args[]) {
        byte b = -34;

        for(int t=128; t > 0; t = t/2) {
            if((b & t) != 0) System.out.print("1 ");
            else System.out.print("0 ");
        }
        System.out.println();

        // reverse all bits
        b = (byte) ~b;
    }
}
for(int t=128; t > 0; t = t/2) {
    if((b & t) != 0) System.out.print("1 ");
    else System.out.print("0 ");
}

Here is the output:

1 1 0 1 1 1 1 0
0 0 1 0 0 0 0 1

The Shift Operators
In Java it is possible to shift the bits that make up a value to the left or to the right by a specified amount. Java defines the three bit-shift operators shown here:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;&lt;</td>
<td>Left shift</td>
</tr>
<tr>
<td>&gt;&gt;</td>
<td>Right shift</td>
</tr>
<tr>
<td>&gt;&gt;&gt;</td>
<td>Unsigned right shift</td>
</tr>
</tbody>
</table>

The general forms for these operators are shown here:

value << num-bits
value >> num-bits
value >>> num-bits

Here, value is the value being shifted by the number of bit positions specified by num-bits.

Each left shift causes all bits within the specified value to be shifted left one position and a 0 bit to be brought in on the right. Each right shift shifts all bits to the right one position and preserves the sign bit. As you may know, negative numbers are usually represented by setting the high-order bit of an integer value to 1. Thus, if the value being shifted is negative, each right shift brings in a 1 on the left. If the value is positive, each right shift brings in a 0 on the left.

In addition to the sign bit, there is something else to be aware of when right shifting. Today, most computers use the two’s complement approach to negative values. In this approach negative values are stored by first reversing the bits in the value and then adding 1. Thus, the byte value for -1 in binary is 1111 1111. Right shifting this value will always produce -1!

If you don’t want to preserve the sign bit when shifting right, you can use an unsigned right shift (>>>), which always brings in a 0 on the left. For this reason, the >>> is also called the zero-fill right shift. You will use the unsigned right shift when shifting bit patterns, such as status codes, that do not represent integers.
For all of the shifts, the bits shifted out are lost. Thus, a shift is not a rotate, and there is no way to retrieve a bit that has been shifted out.

Shown next is a program that graphically illustrates the effect of a left and right shift. Here, an integer is given an initial value of 1, which means that its low-order bit is set. Then, a series of eight shifts are performed on the integer. After each shift, the lower 8 bits of the value are shown. The process is then repeated, except that a 1 is put in the 8th bit position, and right shifts are performed.

```java
// Demonstrate the shift << and >> operators.
class ShiftDemo {
    public static void main(String args[]) {
        int val = 1;

        for(int i = 0; i < 8; i++) {
            for(int t=128; t > 0; t = t/2) {
                if((val & t) != 0) System.out.print("1 ");
                else System.out.print("0 ");
            }
            System.out.println();
            val = val << 1; // left shift
        }
        System.out.println();

        val = 128;
        for(int i = 0; i < 8; i++) {
            for(int t=128; t > 0; t = t/2) {
                if((val & t) != 0) System.out.print("1 ");
                else System.out.print("0 ");
            }
            System.out.println();
            val = val >> 1; // right shift
        }
    }
}
```

The output from the program is shown here:

```
0 0 0 0 0 0 0 1
0 0 0 0 0 0 1 0
0 0 0 0 0 1 0 0
0 0 0 0 1 0 0 0
0 0 0 1 0 0 0 0
0 0 1 0 0 0 0 0
0 1 0 0 0 0 0 0
1 0 0 0 0 0 0 0
```
You need to be careful when shifting `byte` and `short` values because Java will automatically promote these types to `int` when evaluating an expression. For example, if you right shift a `byte` value, it will first be promoted to `int` and then shifted. The result of the shift will also be of type `int`. Often this conversion is of no consequence. However, if you shift a negative `byte` or `short` value, it will be sign-extended when it is promoted to `int`. Thus, the high-order bits of the resulting integer value will be filled with ones. This is fine when performing a normal right shift. But when you perform a zero-fill right shift, there are 24 ones to be shifted before the byte value begins to see zeros.

**Bitwise Shorthand Assignments**

All of the binary bitwise operators have a shorthand form that combines an assignment with the bitwise operation. For example, the following two statements both assign to `x` the outcome of an XOR of `x` with the value 127.

```java
x = x ^ 127;
x ^= 127;
```

**Ask the Expert**

**Q:** Since binary is based on powers of two, can the shift operators be used as a shortcut for multiplying or dividing an integer by two?

**A:** Yes. The bitwise shift operators can be used to perform very fast multiplication or division by two. A shift left doubles a value. A shift right halves it. Of course, this only works as long as you are not shifting bits off one end or the other.
This project creates a class called `ShowBits` that enables you to display in binary the bit pattern for any integer value. Such a class can be quite useful in programming. For example, if you are debugging device-driver code, then being able to monitor the data stream in binary is often a benefit.

### Step by Step

1. Create a file called `ShowBitsDemo.java`.

2. Begin the `ShowBits` class as shown here:

   ```java
   class ShowBits {
       int numbits;

       ShowBits(int n) {
           numbits = n;
       }
   }
   ``

   `ShowBits` creates objects that display a specified number of bits. For example, to create an object that will display the low-order 8 bits of some value, use

   ```java
   ShowBits byteval = new ShowBits(8)
   ``

   The number of bits to display is stored in `numbits`.

3. To actually display the bit pattern, `ShowBits` provides the method `show()`, which is shown here:

   ```java
   void show(long val) {
       long mask = 1;

       // left-shift a 1 into the proper position
       mask <<= numbits-1;

       int spacer = 0;
       for(; mask != 0; mask >>>= 1) {
           if((val & mask) != 0) System.out.print("1");
           else System.out.print("0");
           spacer++;
           if((spacer % 8) == 0) {
               System.out.print(" ");
               spacer = 0;
           }
       }
       System.out.println();
   }
   ```
Notice that \texttt{show()} specifies one \texttt{long} parameter. This does not mean that you always have to pass \texttt{show()} a \texttt{long} value, however. Because of Java’s automatic type promotions, any integer type can be passed to \texttt{show()}. The number of bits displayed is determined by the value stored in \texttt{numbits}. After each group of 8 bits, \texttt{show()} outputs a space. This makes it easier to read the binary values of long bit patterns.

4. The \texttt{ShowBitsDemo} program is shown here:

\begin{verbatim}
/*
 Project 5-3

 A class that displays the binary representation of a value.
 */

class ShowBits {
    int numbits;

    ShowBits(int n) {
        numbits = n;
    }

    void show(long val) {
        long mask = 1;

        // left-shift a 1 into the proper position
        mask <<= numbits-1;

        int spacer = 0;
        for(; mask != 0; mask >>>= 1) {
            if((val & mask) != 0) System.out.print("1");
            else System.out.print("0");
            spacer++;
            if((spacer % 8) == 0) {
                System.out.print(" ");
                spacer = 0;
            }
        }
        System.out.println();
    }
}

// Demonstrate ShowBits.
class ShowBitsDemo {
    public static void main(String args[]) {
        ShowBits b = new ShowBits(8);
        ShowBits i = new ShowBits(32);
    }
}
\end{verbatim}
ShowBits li = new ShowBits(64);

System.out.println("123 in binary: ");
b.show(123);

System.out.println("\n87987 in binary: ");
i.show(87987);

System.out.println("\n237658768 in binary: ");
li.show(237658768);

// you can also show low-order bits of any integer
System.out.println("\nLow order 8 bits of 87987 in binary: ");
b.show(87987);
}
}

5. The output from ShowBitsDemo is shown here:

123 in binary:
01111011

87987 in binary:
00000000 00000001 01010111 10110011

237658768 in binary:
00000000 00000000 00000000 00000000 00001110 00101010 01100010 10010000

Low order 8 bits of 87987 in binary:
10110011

Progress Check

1. To what types can the bitwise operators be applied?

2. What is >>>? 

1. byte, short, int, long, and char.
2. >>> performs an unsigned right shift. This causes a zero to be shifted into the leftmost bit position. It differs from >>, which preserves the sign bit.
The ? Operator

One of Java’s most fascinating operators is the ?. The ? operator is often used to replace if-else statements of this general form:

```java
if (condition)
    var = expression1;
else
    var = expression2;
```

Here, the value assigned to var depends upon the outcome of the condition controlling the if.

The ? is called a ternary operator because it requires three operands. It takes the general form

```
Exp1 ? Exp2 : Exp3;
```

where `Exp1` is a boolean expression, and `Exp2` and `Exp3` are expressions of any type other than void. The type of `Exp2` and `Exp3` must be the same, though. Notice the use and placement of the colon.

The value of a ? expression is determined like this: `Exp1` is evaluated. If it is true, then `Exp2` is evaluated and becomes the value of the entire ? expression. If `Exp1` is false, then `Exp3` is evaluated and its value becomes the value of the expression. Consider this example, which assigns `absval` the absolute value of `val`:

```
absval = val < 0 ? -val : val; // get absolute value of val
```

Here, `absval` will be assigned the value of `val` if `val` is zero or greater. If `val` is negative, then `absval` will be assigned the negative of that value (which yields a positive value). The same code written using the if-else structure would look like this:

```
if(val < 0) absval  = -val;
else absval = val;
```

Here is another example of the ? operator. This program divides two numbers, but will not allow a division by zero.

```java
// Prevent a division by zero using the ?.
class NoZeroDiv {
    public static void main(String args[]) {
        int result;

        for(int i = -5; i < 6; i++) {
            result = i != 0 ? 100 / i : 0;  // This prevents a divide-by-zero.
            if(i != 0)
```

```java
```
System.out.println("100 / " + i + " is " + result);
}
}

The output from the program is shown here:

100 / -5 is -20
100 / -4 is -25
100 / -3 is -33
100 / -2 is -50
100 / -1 is -100
100 / 1 is 100
100 / 2 is 50
100 / 3 is 33
100 / 4 is 25
100 / 5 is 20

Pay special attention to this line from the program:

result = i != 0 ? 100 / i : 0;

Here, `result` is assigned the outcome of the division of 100 by `i`. However, this division takes place only if `i` is not zero. When `i` is zero, a placeholder value of zero is assigned to `result`.

You don’t actually have to assign the value produced by the `?` to some variable. For example, you could use the value as an argument in a call to a method. Or, if the expressions are all of type `boolean`, the `?` can be used as the conditional expression in a loop or `if` statement. For example, here is the preceding program rewritten a bit more efficiently. It produces the same output as before.

// Prevent a division by zero using the ?.
class NoZeroDiv2 {
    public static void main(String args[]) {
        for(int i = -5; i < 6; i++)
            if(i != 0 ? true : false)
                System.out.println("100 / " + i + 
                                    " is " + 100 / i);
    }
}

Notice the `if` statement. If `i` is zero, then the outcome of the `if` is false, the division by zero is prevented, and no result is displayed. Otherwise the division takes place.
Module 5 Mastery Check

1. Show two ways to declare a one-dimensional array of 12 doubles.

2. Show how to initialize a one-dimensional array of integers to the value 1 through 5.

3. Write a program that uses an array to find the average of 10 double values. Use any 10 values you like.

4. Change the sort in Project 5-1 so that it sorts an array of strings. Demonstrate that it works.

5. What is the difference between the String methods indexOf() and lastIndexOf()?

6. Since all strings are objects of type String, show how you can call the length() and charAt() methods on this string literal: "I like Java".

7. Expanding on the Encode cipher class, modify it so that it uses an eight-character string as the key.

8. Can the bitwise operators be applied to the double type?

9. Show how this sequence can be rewritten using the ? operator.
   
   ```java
   if(x < 0) y = 10;
   else y = 20;
   ```

10. In the following fragment, is the & a bitwise or logical operator? Why?
   
   ```java
   boolean a, b;
   // ...
   if(a & b) ... 
   ```

11. Is it an error to overrun the end of an array? Is it an error to index an array with a negative value?

12. What is the unsigned right-shift operator?
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Module 6

A Closer Look at Methods and Classes

**CRITICAL SKILLS**

6.1 Control access to members
6.2 Pass objects to a method
6.3 Return objects from a method
6.4 Overload methods
6.5 Overload constructors
6.6 Use recursion
6.7 Apply static
6.8 Use inner classes
This module resumes our examination of classes and methods. It begins by explaining how to control access to the members of a class. It then discusses the passing and returning of objects, method overloading, recursion, and the use of the keyword `static`. Also described is one of Java’s newer features: nested classes.

**Critical Skill 6.1 Controlling Access to Class Members**

In its support for encapsulation, the class provides two major benefits. First, it links data with the code that manipulates it. You have been taking advantage of this aspect of the class since Module 4. Second, it provides the means by which access to members can be controlled. It is this feature that is examined here.

Although Java’s approach is a bit more sophisticated, in essence, there are two basic types of class members: public and private. A public member can be freely accessed by code defined outside of its class. This is the type of class member that we have been using up to this point. A private member can be accessed only by other methods defined by its class. It is through the use of private members that access is controlled.

Restricting access to a class’s members is a fundamental part of object-oriented programming because it helps prevent the misuse of an object. By allowing access to private data only through a well-defined set of methods, you can prevent improper values from being assigned to that data—by performing a range check, for example. It is not possible for code outside the class to set the value of a private member directly. You can also control precisely how and when the data within an object is used. Thus, when correctly implemented, a class creates a “black box” that can be used, but the inner workings of which are not open to tampering.

Up to this point, you haven’t had to worry about access control because Java provides a default access setting in which the members of a class are freely available to the other code in your program. (Thus, the default access setting is essentially public.) Although convenient for simple classes (and example programs in books such as this one), this default setting is inadequate for many real-world situations. Here you will see how to use Java’s other access control features.

**Java’s Access Specifiers**

Member access control is achieved through the use of three *access specifiers*: `public`, `private`, and `protected`. As explained, if no access specifier is used, the default access setting is assumed. In this module we will be concerned with `public` and `private`. The `protected` specifier applies only when inheritance is involved and is described in Module 8.
When a member of a class is modified by the **public** specifier, that member can be accessed by any other code in your program. This includes methods defined inside other classes.

When a member of a class is specified as **private**, that member can be accessed only by other members of its class. Thus, methods in other classes cannot access a **private** member of another class.

The default access setting (in which no access specifier is used) is the same as **public** unless your program is broken down into packages. A **package** is, essentially, a grouping of classes. Packages are both an organizational and an access control feature, but a discussion of packages must wait until Module 8. For the types of programs shown in this and the preceding modules, **public** access is the same as default access.

An access specifier precedes the rest of a member’s type specification. That is, it must begin a member’s declaration statement. Here are some examples:

```java
public String errMsg;
private accountBalance bal;

private boolean isError(byte status) { // ...
```

To understand the effects of **public** and **private**, consider the following program:

```java
// Public vs private access.
class MyClass {
    private int alpha; // private access
    public int beta; // public access
    int gamma; // default access (essentially public)

    /* Methods to access alpha. It is OK for a
     * member of a class to access a private member
     * of the same class.
     */
    void setAlpha(int a) {
        alpha = a;
    }

    int getAlpha() {
        return alpha;
    }
}

class AccessDemo {
    public static void main(String args[]) {
        MyClass ob = new MyClass();
    }
}
```
/* Access to alpha is allowed only through
   its accessor methods. */
ob.setAlpha(-99);
System.out.println("ob.alpha is " + ob.getAlpha());

// You cannot access alpha like this:
// ob.alpha = 10; // Wrong! alpha is private!

// These are OK because beta and gamma are public.
ob.beta = 88;
obo.gamma = 99;
}
}

As you can see, inside the MyClass class, alpha is specified as private, beta is explicitly
specified as public, and gamma uses the default access, which for this example is the same as
specifying public. Because alpha is private, it cannot be accessed by code outside of its class.
Therefore, inside the AccessDemo class, alpha cannot be used directly. It must be accessed
through its public accessor methods: setAlpha( ) and getAlpha( ). If you were to remove the
comment symbol from the beginning of the following line,

// ob.alpha = 10; // Wrong! alpha is private!

you would not be able to compile this program because of the access violation. Although
access to alpha by code outside of MyClass is not allowed, methods defined within MyClass
can freely access it, as the setAlpha( ) and getAlpha( ) methods show.

The key point is this: a private member can be used freely by other members of its class,
but it cannot be accessed by code outside its class.

To see how access control can be applied to a more practical example, consider the
following program that implements a “fail-soft” int array, in which boundary errors are
prevented, thus avoiding a run-time exception from being generated. This is accomplished
by encapsulating the array as a private member of a class, allowing access to the array only
through member methods. With this approach, any attempt to access the array beyond its
boundaries can be prevented, with such an attempt failing gracefully (resulting in a “soft”
landing rather than a “crash”). The fail-soft array is implemented by the FailSoftArray class,
shown here:

/* This class implements a "fail-soft" array which prevents
   runtime errors. */
class FailSoftArray {
   private int a[]; // reference to array
   private int errval; // value to return if get() fails
public int length; // length is public

/* Construct array given its size and the value to return if get() fails. */
public FailSoftArray(int size, int errv) {
  a = new int[size];
  errval = errv;
  length = size;
}

// Return value at given index.
public int get(int index) {
  if(ok(index)) return a[index];
  return errval;
}

// Put a value at an index. Return false on failure.
public boolean put(int index, int val) {
  if(ok(index)) {
    a[index] = val;
    return true;
  }
  return false;
}

// Return true if index is within bounds.
private boolean ok(int index) {
  if(index >= 0 & index < length) return true;
  return false;
}

// Demonstrate the fail-soft array.
class FSDemo {
  public static void main(String args[]) {
    FailSoftArray fs = new FailSoftArray(5, -1);
    int x;

    // show quiet failures
    System.out.println("Fail quietly.");
    for(int i=0; i < (fs.length * 2); i++)
      fs.put(i, i*10);
    for(int i=0; i < (fs.length * 2); i++) {
      x = fs.get(i);
    }
  }
}

Access to array must be through its accessor methods.
if(x != -1) System.out.print(x + " ");
}
System.out.println(" ");

// now, handle failures
System.out.println("\nFail with error reports.");
for(int i=0; i < (fs.length * 2); i++)
  if(!fs.put(i, i*10))
    System.out.println("Index " + i + " out-of-bounds");

for(int i=0; i < (fs.length * 2); i++) {
  x = fs.get(i);
  if(x != -1) System.out.print(x + " ");
  else
    System.out.println("Index " + i + " out-of-bounds");
}
}
}

The output from the program is shown here:

Fail quietly.
0 10 20 30 40

Fail with error reports.
Index 5 out-of-bounds
Index 6 out-of-bounds
Index 7 out-of-bounds
Index 8 out-of-bounds
Index 9 out-of-bounds
0 10 20 30 40 Index 5 out-of-bounds
Index 6 out-of-bounds
Index 7 out-of-bounds
Index 8 out-of-bounds
Index 9 out-of-bounds

Let’s look closely at this example. Inside FailSoftArray are defined three private members. The first is a, which stores a reference to the array that will actually hold information. The second is errval, which is the value that will be returned when a call to get( ) fails. The third is the private method ok( ), which determines whether an index is within bounds. Thus, these three members can be used only by other members of the FailSoftArray
class. Specifically, a and errval can be used only by other methods in the class, and ok() can
be called only by other members of FailSoftArray. The rest of the class members are public
and can be called by any other code in a program that uses FailSoftArray.

When a FailSoftArray object is constructed, you must specify the size of the array and
the value that you want to return if a call to get() fails. The error value must be a value that
would otherwise not be stored in the array. Once constructed, the actual array referred to by
a and the error value stored in errval cannot be accessed by users of the FailSoftArray object.
Thus, they are not open to misuse. For example, the user cannot try to index a directly, possibly
exceeding its bounds. Access is available only through the get() and put() methods.

The ok() method is private mostly for the sake of illustration. It would be harmless to
make it public because it does not modify the object. However, since it is used internally by
the FailSoftArray class, it can be private.

Notice that the length instance variable is public. This is in keeping with the way Java
implements arrays. To obtain the length of a FailSoftArray, simply use its length member.

To use a FailSoftArray array, call put() to store a value at the specified index. Call get()
to retrieve a value from a specified index. If the index is out-of-bounds, put() returns false
and get() returns errval.

For the sake of convenience, the majority of the examples in this book will continue to
use default access for most members. Remember, however, that in the real world, restricting
access to members—especially instance variables—is an important part of successful object-
oriented programming. As you will see in Module 7, access control is even more vital when
inheritance is involved.

Progress Check

1. Name Java’s access specifiers.
2. Explain what private does.

1. private, public, and protected. A default access is also available.
2. When a member is specified as private, it can be accessed only by other members of its class.
Project 6-1

Improving the Queue Class

You can use the private specifier to make a rather important improvement to the Queue class developed in Module 5, Project 5-2. In that version, all members of the Queue class use the default access, which is essentially public. This means that it would be possible for a program that uses a Queue to directly access the underlying array, possibly accessing its elements out of turn. Since the entire point of a queue is to provide a first-in, first-out list, allowing out-of-order access is not desirable. It would also be possible for a malicious programmer to alter the values stored in the putloc and getloc indices, thus corrupting the queue. Fortunately, these types of problems are easy to prevent by applying the private specifier.

Step by Step

1. Copy the original Queue class in Project 5-2 to a new file called Queue.java.

2. In the Queue class, add the private specifier to the q array, and the indices putloc and getloc, as shown here:

   ```java
   // An improved queue class for characters.
   class Queue {
      // these members are now private
      private char q[]; // this array holds the queue
      private int putloc, getloc; // the put and get indices

      Queue(int size) {
         q = new char[size+1]; // allocate memory for queue
         putloc = getloc = 0;
      }

      // Put a character into the queue.
      void put(char ch) {
         if(putloc == q.length-1) {
            System.out.println(" -- Queue is full.");
            return;
         }

         putloc++;
         q[putloc] = ch;
      }

      // Get a character from the queue.
   }
   ```
char get() {
    if(getloc == putloc) {
        System.out.println("-- Queue is empty.");
        return (char) 0;
    }
    getloc++;
    return q[getloc];
}

3. Changing q, putloc, and getloc from default access to private access has no effect on a program that properly uses Queue. For example, it still works fine with the QDemo class from Project 5-2. However, it prevents the improper use of a Queue. For example, the following types of statements are illegal:

Queue test = new Queue(10);

test.q[0] = 99; // wrong!
test.putloc = -100; // won't work!

4. Now that q, putloc, and getloc are private, the Queue class strictly enforces the first-in, first-out attribute of a queue.

CRITICAL SKILL

6.2 Pass Objects to Methods

Up to this point, the examples in this book have 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 simple program that stores the dimensions of a three-dimensional block:

// Objects can be passed to methods.
class Block {
    int a, b, c;
    int volume;

    Block(int i, int j, int k) {
        a = i;
        b = j;
        c = k;
        volume = a * b * c;
    }
}
// Return true if ob defines same block.
boolean sameBlock(Block ob) {
    if((ob.a == a) & (ob.b == b) & (ob.c == c)) return true;
    else return false;
}

// Return true if ob has same volume.
boolean sameVolume(Block ob) {
    if(ob.volume == volume) return true;
    else return false;
}

class PassOb {
    public static void main(String args[]) {
        Block ob1 = new Block(10, 2, 5);
        Block ob2 = new Block(10, 2, 5);
        Block ob3 = new Block(4, 5, 5);

        System.out.println("ob1 same dimensions as ob2: " +
        ob1.sameBlock(ob2));
        System.out.println("ob1 same dimensions as ob3: " +
        ob1.sameBlock(ob3));
        System.out.println("ob1 same volume as ob3: " +
        ob1.sameVolume(ob3));
    }
}

This program generates the following output:

ob1 same dimensions as ob2: true
ob1 same dimensions as ob3: false
ob1 same volume as ob3: true

The sameBlock( ) and sameVolume( ) methods compare the object passed as a parameter to the invoking object. For sameBlock( ), the dimensions of the objects are compared and true is returned only if the two blocks are the same. For sameVolume( ), the two blocks are compared only to determine whether they have the same volume. In both cases, notice that the parameter ob specifies Block as its type. Although Block is a class type created by the program, it is used in the same way as Java’s built-in types.
How Arguments Are Passed

As the preceding example demonstrated, passing an object to a method is a straightforward task. However, there are some nuances of passing an object that are not shown in the example. In certain cases, the effects of passing an object will be different from those experienced when passing non-object arguments. To see why, you need to understand the two ways in which an argument can be passed to a subroutine.

The first way is call-by-value. This method 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 in the call. The second way an argument can be passed is call-by-reference. In this method, 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, Java uses both methods, depending upon what is passed.

In Java, when you pass a simple type, such as int or double, to a method, it is passed by value. Thus, what occurs to the parameter that receives the argument has no effect outside the method. For example, consider the following program:

```java
// Simple types are passed by value.
class Test {
    /* This method causes no change to the arguments
       used in the call. */
    void noChange(int i, int j) {
        i = i + j;
        j = -j;
    }
}

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.noChange(a, b);
    }
}
```
The output from this program is shown here:

```
a and b before call: 15 20
a and b after call: 15 20
```

As you can see, the operations that occur inside `noChange()` have no effect on the values of `a` and `b` used in the call.

When you pass an object to a method, the situation changes dramatically, because objects are passed 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 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:

```java
// Objects are passed by reference.
class Test {
    int a, b;

    Test(int i, int j) {
        a = i;
        b = j;
    }

    /* Pass an object. Now, ob.a and ob.b in object
     * used in the call will be changed. */
    void change(Test ob) {
        ob.a = ob.a + ob.b;
        ob.b = -ob.b;
    }
}

class CallByRef {
    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.change(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: 35 -20

As you can see, in this case, the actions inside change() have affected the object used as an argument.

As a point of interest, 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 referred to by its corresponding argument.

Ask the Expert

Q: Is there any way that I can pass a simple type by reference?

A: Not directly. However, Java defines a set of classes that wrap the simple types in objects. These are Double, Float, Byte, Short, Integer, Long, and Character. In addition to allowing a simple type to be passed by reference, these wrapper classes define several methods that enable you to manipulate their values. For example, the numeric type wrappers include methods that convert a numeric value from its binary form into its human-readable String form, and vice versa.

Progress Check

1. What is the difference between call-by-value and call-by-reference?
2. How does Java pass simple types? How does it pass objects?

1. In call-by-value, a copy of the argument is passed to a subroutine. In call-by-reference, a reference to the argument is passed.
2. Java passes simple types by value and object types by reference.
Returning Objects

A method can return any type of data, including class types. For example, the class `ErrorMsg` shown here could be used to report errors. Its method, `getErrorMsg()`, returns a `String` object that contains a description of an error based upon the error code that it is passed.

```java
// Return a String object.
class ErrorMsg {
    String msgs[] = {
        "Output Error",
        "Input Error",
        "Disk Full",
        "Index Out-Of-Bounds"
    };

    // Return the error message.
    String getErrorMsg(int i) {
        if(i >=0 & i < msgs.length)
            return msgs[i];
        else
            return "Invalid Error Code";
    }
}

class ErrMsg {
    public static void main(String args[]) {
        ErrorMsg err = new ErrorMsg();

        System.out.println(err.getErrorMsg(2));
        System.out.println(err.getErrorMsg(19));
    }
}
```

Its output is shown here:

```
Disk Full
Invalid Error Code
```

You can, of course, also return objects of classes that you create. For example, here is a reworked version of the preceding program that creates two error classes. One is called `Err`, and it encapsulates an error message along with a severity code. The second is called `ErrorInfo`. It defines a method called `getErrorInfo()`, which returns an `Err` object.
class Err {
    String msg; // error message
    int severity; // code indicating severity of error

    Err(String m, int s) {
        msg = m;
        severity = s;
    }
}

class ErrorInfo {
    String msgs[] = {
        "Output Error",
        "Input Error",
        "Disk Full",
        "Index Out-Of-Bounds"
    };
    int howbad[] = { 3, 3, 2, 4 };

    Err getErrorInfo(int i) {
        if(i >= 0 & i < msgs.length)
            return new Err(msgs[i], howbad[i]);
        else
            return new Err("Invalid Error Code", 0);
    }
}

class ErrInfo {
    public static void main(String args[]) {
        ErrorInfo err = new ErrorInfo();
        Err e;

        e = err.getErrorInfo(2);
        System.out.println(e.msg + " severity: " + e.severity);

        e = err.getErrorInfo(19);
        System.out.println(e.msg + " severity: " + e.severity);
    }
}

Here is the output:

Disk Full severity: 2
Invalid Error Code severity: 0
Each time getErrorInfo() is invoked, a new Err object is created, and a reference to it is returned to the calling routine. This object is then used within main() to display the error message and severity code.

When an object is returned by a method, it remains in existence until there are no more references to it. At that point it is subject to garbage collection. Thus, an object won’t be destroyed just because the method that created it terminates.

**Critical Skill 6.4 Method Overloading**

In this section, you will learn about one of Java’s most exciting features: method overloading. In Java, two or more methods within the same class can 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 implements polymorphism.

In general, to overload a method, simply declare different versions of it. The compiler takes care of the rest. You must observe one important restriction: the type and/or number of the parameters of each overloaded method must differ. It is not sufficient for two methods to differ only in their return types. (Return types do not provide sufficient information in all cases for Java to decide which method to use.) Of course, overloaded methods may differ in their return types, too. When an overloaded method is called, the version of the method whose parameters match the arguments is executed.

Here is a simple example that illustrates method overloading:

```java
// Demonstrate method overloading.
class Overload {
    void ovlDemo() { // First version
        System.out.println("No parameters");
    }

    // Overload ovlDemo for one integer parameter.
    void ovlDemo(int a) { // Second version
        System.out.println("One parameter: " + a);
    }

    // Overload ovlDemo for two integer parameters.
    int ovlDemo(int a, int b) { // Third version
        System.out.println("Two parameters: " + a + " " + b);
        return a + b;
    }

    // Overload ovlDemo for two double parameters.
    double ovlDemo(double a, double b) { // Fourth version
        return a + b;
    }
}
```
class OverloadDemo {
    public static void main(String args[]) {
        Overload ob = new Overload();
        int resI;
        double resD;

        // call all versions of ovlDemo()
        ob.ovlDemo();
        System.out.println();
        ob.ovlDemo(2);
        System.out.println();
        resI = ob.ovlDemo(4, 6);
        System.out.println("Result of ob.ovlDemo(4, 6): " + resI);
        System.out.println();

        resD = ob.ovlDemo(1.1, 2.32);
        System.out.println("Result of ob.ovlDemo(1.1, 2.2): " + resD);
    }
}

This program generates the following output:

No parameters

One parameter: 2

Two parameters: 4 6
Result of ob.ovlDemo(4, 6): 10

Two double parameters: 1.1 2.32
Result of ob.ovlDemo(1.1, 2.2): 3.42

As you can see, ovlDemo() 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 two double parameters. Notice that the first two versions of ovlDemo() return void, and
the second two return a value. This is perfectly valid, but as explained, overloading is not
affected one way or the other by the return type of a method. Thus, attempting to use these
two versions of ov1Demo() will cause an error.

// One ov1Demo(int) is OK.
void ov1Demo(int a) {
    System.out.println("One parameter: "+ a);
}

/* Error! Two ov1Demo(int)s are not OK even though
return types differ.
*/
int ov1Demo(int a) {
    System.out.println("One parameter: "+ a);
    return a * a;
}

As the comments suggest, the difference in their return types is insufficient for the purposes of
overloading.

As you will recall from Module 2, Java provides certain automatic type conversions.
These conversions also apply to parameters of overloaded methods. For example, consider
the following:

/* Automatic type conversions can affect
overloaded method resolution.
*/
class Overload2 {
    void f(int x) {
        System.out.println("Inside f(int): "+ x);
    }

    void f(double x) {
        System.out.println("Inside f(double): "+ x);
    }
}

class TypeConv {
    public static void main(String args[]) {
        Overload2 ob = new Overload2();

        int i = 10;
        double d = 10.1;
byte b = 99;
short s = 10;
float f = 11.5F;

ob.f(i); // calls ob.f(int)
ob.f(d); // calls ob.f(double)

ob.f(b); // calls ob.f(int) -- type conversion
ob.f(s); // calls ob.f(int) -- type conversion
ob.f(f); // calls ob.f(double) -- type conversion
}
}

The output from the program is shown here:

Inside f(int): 10
Inside f(double): 10.1
Inside f(int): 99
Inside f(int): 10
Inside f(double): 11.5

In this example, only two versions of \texttt{f()} are defined: one that has an \texttt{int} parameter and one that has a \texttt{double} parameter. However, it is possible to pass \texttt{f()} a\texttt{byte}, \texttt{short}, or \texttt{float} value. In the case of \texttt{byte} and \texttt{short}, Java automatically converts them to \texttt{int}. Thus, \texttt{f(int)} is invoked. In the case of \texttt{float}, the value is converted to \texttt{double} and \texttt{f(double)} is called.

It is important to understand, however, that the automatic conversions apply only if there is no direct match between a parameter and an argument. For example, here is the preceding program with the addition of a version of \texttt{f()} that specifies a \texttt{byte} parameter:

// Add \texttt{f(byte)}.
class Overload2 {
    void f(byte x) {
        System.out.println("Inside f(byte): "+ x);
    }

    void f(int x) {
        System.out.println("Inside f(int): " + x);
    }

    void f(double x) {
        System.out.println("Inside f(double): " + x);
    }
}
Now when the program is run, the following output is produced:

Inside f(int): 10
Inside f(double): 10.1
Inside f(byte): 99
Inside f(int): 10
Inside f(double): 11.5

In this version, since there is a version of f() that takes a byte argument, when f() is called with a byte argument, f(byte) is invoked and the automatic conversion to int does not occur.

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 to have 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 the 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 correct 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 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.

**Ask the Expert**

**Q:** I’ve heard the term signature used by Java programmers. What is it?

**A:** As it applies to Java, a signature is the name of a method plus its parameter list. Thus, for the purposes of overloading, no two methods within the same class can have the same signature. Notice that a signature does not include the return type since it is not used by Java for overload resolution.
Module 6: A Closer Look at Methods and Classes

Progress Check

1. In order for a method to be overloaded, what condition must be met?
2. Does the return type play a role in method overloading?
3. How does Java’s automatic type conversion affect overloading?

CRITICAL SKILL

Overloading Constructors

Like methods, constructors can also be overloaded. Doing so allows you to construct objects in a variety of ways. For example, consider the following program:

```java
// Demonstrate an overloaded constructor.
class MyClass {
    int x;

    MyClass() {
        System.out.println("Inside MyClass().");
        x = 0;
    }

    MyClass(int i) {
        System.out.println("Inside MyClass(int). ");
        x = i;
    }

    MyClass(double d) {
        System.out.println("Inside MyClass(double). ");
        x = (int) d;
    }

    MyClass(int i, int j) {
        System.out.println("Inside MyClass(int, int). ");
    }
}
```

1. For one method to overload another, the type and/or number of parameters must differ.
2. No. The return type can differ between overloaded methods, but it does not affect method overloading one way or another.
3. When there is no direct match between a set of arguments and a set of parameters, the method with the closest matching set of parameters is used if the arguments can be automatically converted to the type of the parameters.
```java
x = i * j;
}
}

class OverloadConsDemo {
    public static void main(String args[]) {
        MyClass t1 = new MyClass();
        MyClass t2 = new MyClass(88);
        MyClass t3 = new MyClass(17.23);
        MyClass t4 = new MyClass(2, 4);

        System.out.println("t1.x: " + t1.x);
        System.out.println("t2.x: " + t2.x);
        System.out.println("t3.x: " + t3.x);
        System.out.println("t4.x: " + t4.x);
    }
}

The output from the program is shown here:

Inside MyClass().
Inside MyClass(int).
Inside MyClass(double).
Inside MyClass(int, int).
t1.x: 0
t2.x: 88
t3.x: 17
t4.x: 8

MyClass() is overloaded four ways, each constructing an object differently. The proper constructor is called based upon the parameters specified when new is executed. By overloading a class’s constructor, you give the user of your class flexibility in the way objects are constructed.

One of the most common reasons that constructors are overloaded is to allow one object to initialize another. For example, consider this program that uses the Summation class to compute the summation of an integer value.

// Initialize one object with another.
class Summation {
    int sum;
```
Module 6: A Closer Look at Methods and Classes

```java
// Construct from an int.
Summation(int num) {
    sum = 0;
    for(int i=1; i <= num; i++)
        sum += i;
}

// Construct from another object.
Summation(Summation ob) {
    sum = ob.sum;
}

class SumDemo {
    public static void main(String args[]) {
        Summation s1 = new Summation(5);
        Summation s2 = new Summation(s1);

        System.out.println("s1.sum: " + s1.sum);
        System.out.println("s2.sum: " + s2.sum);
    }
}
```

The output is shown here:

```
s1.sum: 15
s2.sum: 15
```

Often, as this example shows, an advantage of providing a constructor that uses one object to initialize another is efficiency. In this case, when s2 is constructed, it is not necessary to recompute the summation. Of course, even in cases when efficiency is not an issue, it is often useful to provide a constructor that makes a copy of an object.

### Progress Check

1. Can a constructor take an object of its own class as a parameter?
2. Why might you want to provide overloaded constructors?

1. Yes.
2. To provide convenience and flexibility to the user of your class.
Project 6-2 Overloading the Queue Constructor

In this project you will enhance the Queue class by giving it two additional constructors. The first will construct a new queue from another queue. The second will construct a queue, giving it initial values. As you will see, adding these constructors enhances the usability of Queue substantially.

Step by Step

1. Create a file called QDemo2.java and copy the updated Queue class from Project 6-1 into it.

2. First, add the following constructor, which constructs a queue from a queue.

   // Construct a Queue from a Queue.
   Queue(Queue ob) {
       putloc = ob.putloc;
       getloc = ob.getloc;
       q = new char[ob.q.length];

       // copy elements
       for(int i=getloc+1; i <= putloc; i++)
           q[i] = ob.q[i];
   }

   Look closely at this constructor. It initializes putloc and getloc to the values contained in the ob parameter. It then allocates a new array to hold the queue and then copies the elements from ob into that array. Once constructed, the new queue will be an identical copy of the original, but both will be completely separate objects.

3. Now add the constructor that initializes the queue from a character array, as shown here:

   // Construct a Queue with initial values.
   Queue(char a[]) {
       putloc = 0;
       getloc = 0;
       q = new char[a.length+1];

       for(int i = 0; i < a.length; i++) put(a[i]);
   }

   This constructor creates a queue large enough to hold the characters in a and then stores those characters in the queue. Because of the way the queue algorithm works, the length of the queue must be 1 greater than the array.

   (continued)
4. Here is the complete updated `Queue` class along with the `QDemo2` class, which demonstrates it:

```java
// A queue class for characters.
class Queue {
    private char q[]; // this array holds the queue
    private int putloc, getloc; // the put and get indices

    // Construct an empty Queue given its size.
    Queue(int size) {
        q = new char[size+1]; // allocate memory for queue
        putloc = getloc = 0;
    }

    // Construct a Queue from a Queue.
    Queue(Queue ob) {
        putloc = ob.putloc;
        getloc = ob.getloc;
        q = new char[ob.q.length];

        // copy elements
        for(int i=getloc+1; i <= putloc; i++)
            q[i] = ob.q[i];
    }

    // Construct a Queue with initial values.
    Queue(char a[]) {
        putloc = 0;
        getloc = 0;
        q = new char[a.length+1];

        for(int i = 0; i < a.length; i++) put(a[i]);
    }

    // Put a character into the queue.
    void put(char ch) {
        if(putloc==q.length-1) {
            System.out.println(" -- Queue is full.");
            return;
        }

        putloc++;
        q[putloc] = ch;
    }

    // Get a character from the queue.
}
char get() {
    if (getloc == putloc) {
        System.out.println("-- Queue is empty.");
        return (char) 0;
    }
    getloc++;
    return q[getloc];
}

// Demonstrate the Queue class.
class QDemo2 {
    public static void main(String args[]) {
        // construct 10-element empty queue
        Queue q1 = new Queue(10);

        char name[] = {'T', 'o', 'm'};
        // construct queue from array
        Queue q2 = new Queue(name);

        char ch;
        int i;

        // put some characters into q1
        for (i = 0; i < 10; i++)
            q1.put((char) ('A' + i));

        // construct queue from another queue
        Queue q3 = new Queue(q1);

        // Show the queues.
        System.out.print("Contents of q1: ");
        for (i = 0; i < 10; i++) {
            ch = q1.get();
            System.out.print(ch);
        }
        System.out.println(" \n");

        System.out.print("Contents of q2: ");
        for (i = 0; i < 3; i++) {
            ch = q2.get();
            System.out.print(ch);
        }
    }
}

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

System.out.print("Contents of q3: ");
for(i=0; i < 10; i++) {
    ch = q3.get();
    System.out.print(ch);
}

The output from the program is shown here:

Contents of q1: ABCDEFGHIJ

Contents of q2: Tom

Contents of q3: ABCDEFGHIJ

**CRITICAL SKILL 6.6 Recursion**

In Java, a method can call itself. This process is called *recursion*, and a method that calls itself is said to be *recursive*. In general, recursion is the process of defining something in terms of itself and is somewhat similar to a circular definition. The key component of a recursive method is a statement that executes a call to itself. Recursion is a powerful control mechanism.

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 x 2 x 3, or 6. The following program shows a recursive way to compute the factorial of a number. For comparison purposes, a nonrecursive equivalent is also included.

```java
// A simple example of recursion.
class Factorial {
    // This is a recursive function.
    int factR(int n) {
        int result;

        if(n==1) return 1;
        result = factR(n-1) * n;
        return result;
    }

    // This is an iterative equivalent.
    int factI(int n) {
        int t, result;
```
result = 1;
for (t=1; t <= n; t++) result *= t;
return result;
}

class Recursion {
    public static void main(String args[]) {
        Factorial f = new Factorial();
        System.out.println("Factorials using recursive method.");
        System.out.println("Factorial of 3 is " + f.factR(3));
        System.out.println("Factorial of 4 is " + f.factR(4));
        System.out.println("Factorial of 5 is " + f.factR(5));
        System.out.println();
        System.out.println("Factorials using iterative method.");
        System.out.println("Factorial of 3 is " + f.factI(3));
        System.out.println("Factorial of 4 is " + f.factI(4));
        System.out.println("Factorial of 5 is " + f.factI(5));
    }
}

The output from this program is shown here:

    Factorials using recursive method.
    Factorial of 3 is 6
    Factorial of 4 is 24
    Factorial of 5 is 120

    Factorials using iterative method.
    Factorial of 3 is 6
    Factorial of 4 is 24
    Factorial of 5 is 120

The operation of the nonrecursive method factI( ) should be clear. It uses a loop starting at 1 and progressively multiplies each number by the moving product.

The operation of the recursive factR( ) is a bit more complex. When factR( ) is called with an argument of 1, the method returns 1; otherwise it returns the product of factR(n–1)*n. To evaluate this expression, factR( ) is called with n–1. This process repeats until n equals 1 and the calls to the method begin returning. For example, when the factorial of 2 is calculated, the first call to factR( ) will cause a second call to be made with an argument of 1. This call will return 1, which is then multiplied by 2 (the original value of n). The answer is then 2. You might find it interesting to insert println( ) statements into factR( ) that show at what level each call is, and what the intermediate results 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. A recursive call does not make a new copy of the method. Only the arguments are new. 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. Too many 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, you probably will not have to worry about this unless a recursive routine runs wild.

The main advantage to recursion is that some types of algorithms can be implemented more clearly and simply recursively than they can be iteratively. For example, the Quicksort sorting algorithm is quite difficult to implement in an iterative way. Also, some problems, especially AI-related ones, seem to lend themselves to recursive solutions.

When writing recursive methods, you must have a conditional statement, such as an if, 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 type of error is very common when working with recursion. Use println( ) statements liberally so that you can watch what is going on and abort execution if you see that you have made a mistake.

**CRITICAL SKILL 6.7 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 through an object of its class, but 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 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 by the operating system when your program begins.

Outside the class, to use a static member, you need only specify the name of its class followed by the dot operator. No object needs to be created. For example, if you want to assign the value 10 to a static variable called count that is part of the Timer class, use this line:

```java
Timer.count = 10;
```
This format is similar to that used to access normal instance variables through an object, except that the class name is used. A static method can be called in the same way—by use of the dot operator on the name of the class.

Variables declared as static are, essentially, global variables. When an object is declared, no copy of a static variable is made. Instead, all instances of the class share the same static variable. Here is an example that shows the differences between a static variable and an instance variable:

```java
// Use a static variable.
class StaticDemo {
    int x; // a normal instance variable
    static int y; // a static variable
}

class SDemo {
    public static void main(String args[]) {
        StaticDemo ob1 = new StaticDemo();
        StaticDemo ob2 = new StaticDemo();

        /* Each object has its own copy of
         * an instance variable. */
        ob1.x = 10;
        ob2.x = 20;
        System.out.println("Of course, ob1.x and ob2.x " +
            "are independent.");
        System.out.println("ob1.x: " + ob1.x +
            "\nob2.x: " + ob2.x);
        System.out.println();

        /* Each object shares one copy of
         * a static variable. */
        System.out.println("The static variable y is shared.");
        ob1.y = 19;
        System.out.println("ob1.y: " + ob1.y +
            "\nob2.y: " + ob2.y);
        System.out.println();

        System.out.println("The static variable y can be" +
            " accessed through its class.");
        StaticDemo.y = 11; // Can refer to y through class name
        System.out.println("StaticDemo.y: " + StaticDemo.y +
            "\nob1.y: " + ob1.y +
            "\nob2.y: " + ob2.y);
    }
}
```
The output from the program is shown here:

Of course, ob1.x and ob2.x are independent.

ob1.x: 10
ob2.x: 20

The static variable y is shared.

ob1.y: 19
ob2.y: 19

The static variable y can be accessed through its class.

StaticDemo.y: 11
ob1.y: 11
ob2.y: 11

As you can see, the static variable y is shared by both ob1 and ob2. Changing it through one instance implies that it is changed for all instances. Furthermore, y can be accessed either through an object name, as in ob2.y, or through its class name, as in StaticDemo.y.

The difference between a static method and a normal method is that the static method can be called through its class name, without any object of that class being created. You have seen an example of this already: the sqrt() method, which is a static method within Java’s standard Math class. Here is an example that creates a static method:

```java
// Use a static method.
class StaticMeth {
    static int val = 1024; // a static variable

    // a static method
    static int valDiv2() {
        return val/2;
    }
}

class SDemo2 {
    public static void main(String args[]) {
        System.out.println("val is " + StaticMeth.val);
        System.out.println("StaticMeth.valDiv2(): " +
            StaticMeth.valDiv2());

        StaticMeth.val = 4;
        System.out.println("val is " + StaticMeth.val);
        System.out.println("StaticMeth.valDiv2(): " +
            StaticMeth.valDiv2());
    }
}
```
Methods declared as static have several restrictions:

- They can call only other static methods.
- They must access only static data.
- They do not have a this reference.

For example, in the following class, the static method `valDivDenom()` is illegal.

class StaticError {
    int denom = 3; // a normal instance variable
    static int val = 1024; // a static variable

    /* Error! Can't access a non-static variable
    from within a static method. */
    static int valDivDenom() {
        return val/denom; // won't compile!
    }
}

Here, `denom` is a normal instance variable that cannot be accessed within a static method.

**Static Blocks**

Sometimes a class will require some type of initialization before it is ready to create objects. For example, it might need to establish a connection to a remote site. It also might need to initialize certain static variables before any of the class’s static methods are used. To handle these types of situations Java allows you to declare a static block. A static block is executed when the class is first loaded. Thus, it is executed before the class can be used for any other purpose. Here is an example of a static block:

```java
// Use a static block
class StaticBlock {
    static double rootOf2;
    static double rootOf3;
```
static {
    System.out.println("Inside static block.");
    rootOf2 = Math.sqrt(2.0);
    rootOf3 = Math.sqrt(3.0);
}

StaticBlock(String msg) {
    System.out.println(msg);
}
}
class SDemo3 {
    public static void main(String args[]) {
        StaticBlock ob = new StaticBlock("Inside Constructor");

        System.out.println("Square root of 2 is " +
                StaticBlock.rootOf2);
        System.out.println("Square root of 3 is " +
                StaticBlock.rootOf3);
    }
}
}

The output is shown here:

Inside static block.
Inside Constructor
Square root of 2 is 1.4142135623730951
Square root of 3 is 1.7320508075688772

As you can see, the static block is executed before any objects are constructed.

Progress Check

1. Define recursion.
2. Explain the difference between static variables and instance variables.
3. When is a static block executed?

1. Recursion is the process of a method calling itself.
2. Each object of a class has its own copy of the instance variables defined by the class. Each object of a class shares one copy of a static variable.
3. A static block is executed when its class is first loaded, before its first use.
The Quicksort

In Module 5 you were shown a simple sorting method called the Bubble sort. It was mentioned at the time that substantially better sorts exist. Here you will develop a version of one of the best: the Quicksort. The Quicksort, invented and named by C.A.R. Hoare, is the best general-purpose sorting algorithm currently available. The reason it could not be shown in Module 5 is that the best implementations of the Quicksort rely on recursion. The version we will develop sorts a character array, but the logic can be adapted to sort any type of object you like.

The Quicksort is built on the idea of partitions. The general procedure is to select a value, called the *comparand*, and then to partition the array into two sections. All elements greater than or equal to the partition value are put on one side, and those less than the value are put on the other. This process is then repeated for each remaining section until the array is sorted. For example, given the array *fedacb* and using the value *d* as the comparand, the first pass of the Quicksort would rearrange the array as follows:

<table>
<thead>
<tr>
<th>Initial</th>
<th>fedacb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pass1</td>
<td>bca def</td>
</tr>
</tbody>
</table>

This process is then repeated for each section—that is, *bca* and *def*. As you can see, the process is essentially recursive in nature, and indeed, the cleanest implementation of Quicksort is as a recursive function.

You can select the comparand value in two ways. You can either choose it at random, or you can select it by averaging a small set of values taken from the array. For optimal sorting, you should select a value that is precisely in the middle of the range of values. However, this is not easy to do for most sets of data. In the worst case, the value chosen is at one extremity. Even in this case, however, Quicksort still performs correctly. The version of Quicksort that we will develop selects the middle element of the array as the comparand.

**Step by Step**

1. Create a file called *QSDemo.java*.

2. First, create the *Quicksort* class shown here:

```java
// Project 6-3: A simple version of the Quicksort.
class Quicksort {

    // Set up a call to the actual Quicksort method.
    static void qsort(char items[]) {
        qs(items, 0, items.length-1);
    }

    // (continued)

    (continued)
```
// A recursive version of Quicksort for characters.
private static void qs(char items[], int left, int right)
{
    int i, j;
    char x, y;

    i = left; j = right;
    x = items[(left+right)/2];

    do {
        while((items[i] < x) && (i < right)) i++;
        while((x < items[j]) && (j > left)) j--;

        if(i <= j) {
            y = items[i];
            items[i] = items[j];
            items[j] = y;
            i++; j--;
        }
    } while(i <= j);

    if(left < j) qs(items, left, j);
    if(i < right) qs(items, i, right);
}

To keep the interface to the Quicksort simple, the Quicksort class provides the qsort() method, which sets up a call to the actual Quicksort method, qs(). This enables the Quicksort to be called with just the name of the array to be sorted, without having to provide an initial partition. Since qs() is only used internally, it is specified as private.

3. To use the Quicksort, simply call Quicksort.qsort(). Since qsort() is specified as static, it can be called through its class rather than on an object. Thus, there is no need to create a Quicksort object. After the call returns, the array will be sorted. Remember, this version works only for character arrays, but you can adapt the logic to sort any type of arrays you want.

4. Here is a program that demonstrates Quicksort:

    // Project 6-3: A simple version of the Quicksort.
class Quicksort {

    // Set up a call to the actual Quicksort method.
    static void qsort(char items[]) {
        qs(items, 0, items.length-1);
    }

// A recursive version of Quicksort for characters.
private static void qs(char items[], int left, int right) {
    int i, j;
    char x, y;

    i = left; j = right;
    x = items[(left+right)/2];

    do {
        while((items[i] < x) && (i < right)) i++;
        while((x < items[j]) && (j > left)) j--;

        if(i <= j) {
            y = items[i];
            items[i] = items[j];
            items[j] = y;
            i++; j--;
        }
    } while(i <= j);

    if(left < j) qs(items, left, j);
    if(i < right) qs(items, i, right);
}

class QSDemo {
    public static void main(String args[]) {
        char a[] = { 'd', 'x', 'a', 'r', 'p', 'j', 'i' };
        int i;

        System.out.print("Original array: ");
        for(i=0; i < a.length; i++)
            System.out.print(a[i]);
        System.out.println();

        // now, sort the array
        Quicksort.qsort(a);

        System.out.print("Sorted array: ");
        for(i=0; i < a.length; i++)
            System.out.print(a[i]);
    }
}
Introducing Nested and Inner Classes

In Java you can define a nested class. This is a class that is declared within another class. Frankly, the nested class is a somewhat advanced topic. In fact, nested classes were not even allowed in the first version of Java. It was not until Java 1.1 that they were added. However, it is important that you know what they are and the mechanics of how they are used because they can be effectively employed by some types of applets.

A nested class is known only to its enclosing class. Thus, the scope of a nested class is limited to that of its outer class. 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.

There are two general types of nested classes: those that are preceded by the static modifier and those that are not. The only type that we are concerned about in this book is the non-static variety. This type of nested class is also called an inner 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.

Sometimes an inner class is used to provide a set of services that is used only by its enclosing class. Here is an example that uses an inner class to compute various values for its enclosing class:

```java
// Use an inner class.
class Outer {
    int nums[];

    Outer(int n[]) {
        nums = n;
    }

    void Analyze() {
        Inner inOb = new Inner();

        System.out.println("Minimum: "+ inOb.min());
        System.out.println("Maximum: "+ inOb.max());
        System.out.println("Average: "+ inOb.avg());
    }
}

// This is an inner class.
class Inner {
    int min() {
        int m = nums[0];
        return m;
    }
}
```
for(int i=1; i < nums.length; i++)
    if(nums[i] < m) m = nums[i];

    return m;
}

int max() {
    int m = nums[0];
    for(int i=1; i < nums.length; i++)
        if(nums[i] > m) m = nums[i];

    return m;
}

int avg() {
    int a = 0;
    for(int i=0; i < nums.length; i++)
        a += nums[i];

    return a / nums.length;
}
}
}

class NestedClassDemo {
    public static void main(String args[]) {
        int x[] = { 3, 2, 1, 5, 6, 9, 7, 8 };
        Outer outOb = new Outer(x);

        outOb.Analyze();
    }
}

The output from the program is shown here:

Minimum:  1
Maximum:  9
Average:  5

In this example, the inner class Inner computes various values from the array nums, which is a member of Outer. As explained, a nested class has access to the members of its enclosing class, so it is perfectly acceptable for Inner to access the nums array directly. Of course, the opposite is not true. For example, it would not be possible for analyze() to invoke the min() method directly, without creating an Inner object.
It is possible to nest a class within any block scope. Doing so simply creates a localized class that is not known outside its block. The following example adapts the `ShowBits` class developed in Project 5-2 for use as a local class.

```java
// Use ShowBits as a local class.
class LocalClassDemo {
    public static void main(String args[]) {

        // An inner class version of ShowBits.
        class ShowBits {
            int numbits;

            ShowBits(int n) {
                numbits = n;
            }

            void show(long val) {
                long mask = 1;

                // left-shift a 1 into the proper position
                mask <<= numbits-1;

                int spacer = 0;
                for(; mask != 0; mask >>= 1) {
                    if((val & mask) != 0) System.out.print("1");
                    else System.out.print("0");
                    spacer++;
                    if((spacer % 8) == 0) {
                        System.out.print(" ");
                        spacer = 0;
                    }
                }
                System.out.println();
            }
        }

        for(byte b = 0; b < 10; b++) {
            ShowBits byteval = new ShowBits(8);
        }
    }
}
```
System.out.print(b + " in binary: ");
byteval.show(b);
}
}

The output from this version of the program is shown here:

0 in binary: 00000000
1 in binary: 00000001
2 in binary: 00000010
3 in binary: 00000011
4 in binary: 00000100
5 in binary: 00000101
6 in binary: 00000110
7 in binary: 00000111
8 in binary: 00001000
9 in binary: 00001001

In this example, the ShowBits class is not known outside of main(), and any attempt to access it by any method other than main() will result in an error.

One last point: you can create an inner class that does not have a name. This is called an anonymous inner class. An object of an anonymous inner class is instantiated when the class is declared, using new.

Ask the Expert

Q: What makes a static nested class different from a non-static one?

A: A static nested class is one that has the static modifier applied. Because it is static, it can access only other static members of the enclosing class directly. It must access other members of its outer class through an object reference.
Module 6 Mastery Check

1. Given this fragment,
   
   ```java
class X {
    private int count;
}
```

   is the following fragment correct?

   ```java
class Y {
    public static void main(String args[]) {
     X ob = new X();
     ob.count = 10;
    }
}
```

2. An access specifier must __________ a member’s declaration.

3. The complement of a queue is a stack. It uses first-in, last-out accessing and is often likened to a stack of plates. The first plate put on the table is the last plate used. Create a stack class called **Stack** that can hold characters. Call the methods that access the stack `push()` and `pop()`. Allow the user to specify the size of the stack when it is created. Keep all other members of the **Stack** class private. (Hint: you can use the **Queue** class as a model; just change the way the data is accessed.)

4. Given this class,
   
   ```java
class Test {
    int a;
    Test(int i) { a = i; }
}
```

   write a method called `swap()` that exchanges the contents of the objects referred to by two **Test** object references.

5. Is the following fragment correct?
   
   ```java
class X {
    int meth(int a, int b) { ... }
    String meth(int a, int b) { ... }
}
```

6. Write a recursive method that displays the contents of a string backwards.

7. If all objects of a class need to share the same variable, how must you declare that variable?

8. Why might you need to use a **static** block?

9. What is an inner class?
10. To make a member accessible by only other members of its class, what access specifier must be used?

11. The name of a method plus its parameter list constitutes the method’s ________________.

12. An int argument is passed to a method by using call-by-______________.
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**Module 7**

Inheritance

---

**CRITICAL SKILLS**

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Inheritance is one of the three foundation principles 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 language 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 variables and methods defined by the superclass and adds its own, unique elements.

### Critical Skill

#### 7.1 Inheritance Basics

Java supports inheritance by allowing one class to incorporate another class into its declaration. This is done by using the `extends` keyword. Thus, the subclass adds to (extends) the superclass.

Let’s begin with a short example that illustrates several of the key features of inheritance. The following program creates a superclass called `TwoDShape`, which stores the width and height of a two-dimensional object, and a subclass called `Triangle`. Notice how the keyword `extends` is used to create a subclass.

```java
// A simple class hierarchy.

// A class for two-dimensional objects.
class TwoDShape {
    double width;
    double height;

    void showDim() {
        System.out.println("Width and height are "+
                              width + " and " + height);
    }
}

// A subclass of TwoDShape for triangles.
class Triangle extends TwoDShape {
    String style;

    double area() {
        return width * height / 2;
    }

    void showStyle() {
        System.out.println("Triangle is "+style);
    }
}
```

Triangle inherits TwoDShape. Triangle can refer to the members of TwoDShape as if they were part of Triangle.
class Shapes {
    public static void main(String args[]) {
        Triangle t1 = new Triangle();
        Triangle t2 = new Triangle();

        t1.width = 4.0;
        t1.height = 4.0;
        t1.style = "isosceles";

        t2.width = 8.0;
        t2.height = 12.0;
        t2.style = "right";

        System.out.println("Info for t1: ");
        t1.showStyle();
        t1.showDim();
        System.out.println("Area is " + t1.area());

        System.out.println();

        System.out.println("Info for t2: ");
        t2.showStyle();
        t2.showDim();
        System.out.println("Area is " + t2.area());
    }
}

The output from this program is shown here:

Info for t1:
Triangle is isosceles
Width and height are 4.0 and 4.0
Area is 8.0

Info for t2:
Triangle is right
Width and height are 8.0 and 12.0
Area is 48.0

Here, TwoDShape defines the attributes of a “generic” two-dimensional shape, such as a square, rectangle, triangle, and so on. The Triangle class creates a specific type of TwoDShape, in this case, a triangle. The Triangle class includes all of TwoDObject and adds the field style,
the method \texttt{area()} \texttt{, and the method showStyle().} A description of the type of triangle is stored in \texttt{style, area()} computes and returns the area of the triangle, and \texttt{showStyle()} displays the triangle style.

Because \texttt{Triangle} includes all of the members of its superclass, \texttt{TwoDShape}, it can access \texttt{width} and \texttt{height} inside \texttt{area()}. Also, inside \texttt{main()}, objects \texttt{t1 and t2} can refer to \texttt{width} and \texttt{height} directly, as if they were part of \texttt{Triangle}. Figure 7-1 depicts conceptually how \texttt{TwoDShape} is incorporated into \texttt{Triangle}.

Even though \texttt{TwoDShape} is a superclass for \texttt{Triangle}, 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. For example, the following is perfectly valid.

\begin{verbatim}
TwoDShape shape = new TwoDShape();
shape.width = 10;
shape.height = 20;
shape.showDim();
\end{verbatim}

Of course, an object of \texttt{TwoDShape} has no knowledge of or access to any subclasses of \texttt{TwoDShape}.

The general form of a \texttt{class} declaration that inherits a superclass is shown here:

\begin{verbatim}
class \texttt{subclass-name} extends \texttt{superclass-name} {  
  // body of class
}
\end{verbatim}

You can specify only one superclass for any subclass that you create. Java does not support the inheritance of multiple superclasses into a single subclass. (This differs from C++, in which you can inherit multiple base classes. Be aware of this when converting C++ code to Java.) You can, however, create a hierarchy of inheritance in which a subclass becomes a superclass of another subclass. Of course, no class can be a superclass of itself.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{P:\010Comp\Begin8\588-2\ch07.vp}
\caption{A conceptual depiction of the 	exttt{Triangle} class}
\end{figure}
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, here is
another subclass of TwoDShape that encapsulates rectangles.

```java
// A subclass of TwoDShape for rectangles.
class Rectangle extends TwoDShape {
    boolean isSquare() {
        if(width == height) return true;
        return false;
    }

    double area() {
        return width * height;
    }
}
```

The Rectangle class includes TwoDShape and adds the methods isSquare(), which
determines if the rectangle is square, and area(), which computes the area of a rectangle.

Member Access and Inheritance

As you learned in Module 6, often an instance variable of a class will be declared private to
prevent its unauthorized use or tampering. Inheriting a class does not overrule the private
access restriction. Thus, even though a subclass includes all of the members of its superclass, it
cannot access those members of the superclass that have been declared private. For example,
if, as shown here, width and height are made private in TwoDShape, then Triangle will not
be able to access them.

```java
// Private members are not inherited.

// This example will not compile.

// A class for two-dimensional objects.
class TwoDShape {
    private double width;  // these are
    private double height; // now private

    void showDim() {
        System.out.println("Width and height are "+
                        width + " and " + height);
    }
}
```
// A subclass of TwoDShape for triangles.
class Triangle extends TwoDShape {
    String style;

    double area() {
        return width * height / 2; // Error! can't access
    }

    void showStyle() {
        System.out.println("Triangle is "+style);
    }
}

The Triangle class will not compile because the reference to width and height inside the area() method causes an access violation. Since width and height are declared private, they are accessible only by other members of their own class. Subclasses have no access to them.

Remember that a class member that has been declared private will remain private to its class. It is not accessible by any code outside its class, including subclasses.

At first, you might think that the fact that subclasses do not have access to the private members of superclasses is a serious restriction that would prevent the use of private members in many situations. However this is not true. As explained in Module 6, Java programmers typically grant access to the private members of a class through accessor methods. Here is a rewrite of the TwoDShape and Triangle classes that uses methods to access the private instance variables width and height.

// Use accessor methods to set and get private members.

// A class for two-dimensional objects.
class TwoDShape {
    private double width; // these are private double height; // now private

    // Accessor methods for width and height.
    double getWidth() { return width; }
    double getHeight() { return height; }
    void setWidth(double w) { width = w; }
    void setHeight(double h) { height = h; }

    void showDim() {
        System.out.println("Width and height are "+width + " and "+height);
    }
}
// A subclass of TwoDShape for triangles.
class Triangle extends TwoDShape {
    String style;

    double area() {
        return getWidth() * getHeight() / 2;
    }

    void showStyle() {
        System.out.println("Triangle is " + style);
    }
}

class Shapes2 {
    public static void main(String args[]) {
        Triangle t1 = new Triangle();
        Triangle t2 = new Triangle();

        t1.setWidth(4.0);
        t1.setHeight(4.0);
        t1.style = "isosceles";

        t2.setWidth(8.0);
        t2.setHeight(12.0);
        t2.style = "right";

        System.out.println("Info for t1: ");
        t1.showStyle();
        t1.showDim();
        System.out.println("Area is " + t1.area());

        System.out.println();

        System.out.println("Info for t2: ");
        t2.showStyle();
        t2.showDim();
        System.out.println("Area is " + t2.area());
    }
}
Ask the Expert

Q: When should I make an instance variable private?

A: There are no hard and fast rules, but here are two general principles. If an instance variable is to be used only by methods defined within its class, then it should be made private. If an instance variable must be within certain bounds, then it should be private and made available only through accessor methods. This way, you can prevent invalid values from being assigned.

Progress Check

1. When creating a subclass, what keyword is used to include a superclass?

2. Does a subclass include the members of its superclass?

3. Does a subclass have access to the private members of its superclass?

Constructors and Inheritance

In a hierarchy, it is possible for both superclasses and subclasses to have their own constructors. This raises an important question: what constructor is responsible for building an object of the subclass—the one in the superclass, the one in the subclass, or both? The answer is this: the constructor for the superclass constructs the superclass portion of the object, and the constructor for the subclass constructs the subclass part. This makes sense because the superclass has no knowledge of or access to any element in a subclass. Thus, their construction must be separate. The preceding examples have relied upon the default constructors created automatically by Java, so this was not an issue. However, in practice, most classes will have explicit constructors. Here you will see how to handle this situation.
When only the subclass defines a constructor, the process is straightforward: simply construct the subclass object. The superclass portion of the object is constructed automatically using its default constructor. For example, here is a reworked version of Triangle that defines a constructor. It also makes style private since it is now set by the constructor.

```java
// Add a constructor to Triangle.

// A class for two-dimensional objects.
class TwoDShape {
    private double width; // these are
    private double height; // now private

    // Accessor methods for width and height.
    double getWidth() { return width; }
    double getHeight() { return height; }
    void setWidth(double w) { width = w; }
    void setHeight(double h) { height = h; }

    void showDim() {
        System.out.println("Width and height are "+
                        width + " and " + height);
    }
}

// A subclass of TwoDShape for triangles.
class Triangle extends TwoDShape {
    private String style;

    // Constructor
    Triangle(String s, double w, double h) {
        setWidth(w);
        setHeight(h);

        style = s;
    }

    double area() {
        return getWidth() * getHeight() / 2;
    }

    void showStyle() {
        System.out.println("Triangle is "+ style);
    }
}
```
class Shapes3 {
    public static void main(String args[]) {
        Triangle t1 = new Triangle("isosceles", 4.0, 4.0);
        Triangle t2 = new Triangle("right", 8.0, 12.0);

        System.out.println("Info for t1: ");
        t1.showStyle();
        t1.showDim();
        System.out.println("Area is " + t1.area());

        System.out.println();

        System.out.println("Info for t2: ");
        t2.showStyle();
        t2.showDim();
        System.out.println("Area is " + t2.area());
    }
}

Here, Triangle’s constructor initializes the members of TwoDClass that it inherits along with its own style field.

When both the superclass and the subclass define constructors, the process is a bit more complicated because both the superclass and subclass constructors must be executed. In this case you must use another of Java’s keywords, super, which has two general forms. The first calls a superclass constructor. The second is used to access a member of the superclass that has been hidden by a member of a subclass. Here, we will look at its first use.

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(parameter-list);

Here, parameter-list specifies any parameters 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 the version of TwoDShape in the following program. It defines a constructor that initializes width and height.
// Add constructors to TwoDShape.
class TwoDShape {
    private double width;
    private double height;

    // Parameterized constructor.
    TwoDShape(double w, double h) {
        width = w;
        height = h;
    }

    // Accessor methods for width and height.
    double getWidth() { return width; }
    double getHeight() { return height; }
    void setWidth(double w) { width = w; }
    void setHeight(double h) { height = h; }

    void showDim() {
        System.out.println("Width and height are "+
                         width + " and " + height);
    }
}

// A subclass of TwoDShape for triangles.
class Triangle extends TwoDShape {
    private String style;

    Triangle(String s, double w, double h) {
        super(w, h); // call superclass constructor
        style = s;
    }

    double area() {
        return getWidth() * getHeight() / 2;
    }

    void showStyle() {
        System.out.println("Triangle is " + style);
    }
}
class Shapes4 {
    public static void main(String args[]) {
        Triangle t1 = new Triangle("isosceles", 4.0, 4.0);
        Triangle t2 = new Triangle("right", 8.0, 12.0);

        System.out.println("Info for t1: ");
        t1.showStyle();
        t1.showDim();
        System.out.println("Area is " + t1.area());

        System.out.println();

        System.out.println("Info for t2: ");
        t2.showStyle();
        t2.showDim();
        System.out.println("Area is " + t2.area());
    }
}

Here, Triangle() calls super() with the parameters \texttt{w} and \texttt{h}. This causes the TwoDShape() constructor to be called, which initializes \texttt{width} and \texttt{height} using these values. Triangle no longer initializes these values itself. It need only initialize the value unique to it: \texttt{style}. This leaves TwoDShape free to construct its subobject in any manner that it so chooses. Furthermore, TwoDShape can add functionality about which existing subclasses have no knowledge, thus preventing existing code from breaking.

Any form of constructor defined by the superclass can be called by super(). The constructor executed will be the one that matches the arguments. For example, here are expanded versions of both TwoDShape and Triangle that include default constructors and constructors that take one argument.

// Add more constructors to TwoDShape.
class TwoDShape {
    private double width;
    private double height;

    // A default constructor.
    TwoDShape() {
        width = height = 0.0;
    }
}
// Parameterized constructor.
TwoDShape(double w, double h) {
    width = w;
    height = h;
}

// Construct object with equal width and height.
TwoDShape(double x) {
    width = height = x;
}

// Accessor methods for width and height.
double getWidth() { return width; }
double getHeight() { return height; }
void setWidth(double w) { width = w; }
void setHeight(double h) { height = h; }

void showDim() {
    System.out.println("Width and height are "+
        width + " and " + height);
}
}

// A subclass of TwoDShape for triangles.
class Triangle extends TwoDShape {
    private String style;

    // A default constructor.
    Triangle() {
        super();
        style = "null";
    }

    // Constructor
    Triangle(String s, double w, double h) {
        super(w, h); // call superclass constructor
        style = s;
    }

    // Construct an isosceles triangle.
    Triangle(double x) {
        super(x); // call superclass constructor
    }

    // A constructor with a parameterized form.
    Triangle(double w, double h) {
        super(w, h);
        style = "isosceles";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "right triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double a, double b) {
        super(a, b);
        style = "obtuse triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "acute triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "right triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "isosceles triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "scalene triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "right triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "isosceles triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "scalene triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "right triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "isosceles triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "scalene triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "right triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "isosceles triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "scalene triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "right triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "isosceles triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "scalene triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "right triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "isosceles triangle";
    }

    // A constructor with a parameterized form.
    Triangle(double x) {
        super(x);
        style = "scalene triangle";
    }
class Shapes5 {
  public static void main(String args[]) {
    Triangle t1 = new Triangle()
    Triangle t2 = new Triangle("right", 8.0, 12.0)
    Triangle t3 = new Triangle(4.0);

    t1 = t2;

    System.out.println("Info for t1: ");
    t1.showStyle();
    t1.showDim();
    System.out.println("Area is " + t1.area());

    System.out.println();

    System.out.println("Info for t2: ");
    t2.showStyle();
    t2.showDim();
    System.out.println("Area is " + t2.area());

    System.out.println();

    System.out.println("Info for t3: ");
    t3.showStyle();
    t3.showDim();
    System.out.println("Area is " + t3.area());
  }
}

Here is the output from this version.

Info for t1:
Triangle is right
Width and height are 8.0 and 12.0
Area is 48.0

Info for t2:
Triangle is right
Width and height are 8.0 and 12.0
Area is 48.0

Info for t3:
Triangle is isosceles
Width and height are 4.0 and 4.0
Area is 8.0

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 multilevel hierarchy. Also, super() must always be the first statement executed inside a subclass constructor.

Progress Check

1. How does a subclass execute its superclass’ constructor?
2. Can parameters be passed via super()?
3. Can super() go anywhere within a subclass’ constructor?

1. It calls super().
2. Yes.
3. No, it must be the first statement executed.
Using super to Access Superclass Members

There is a second form of `super` that 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:

\[ \text{super}. \text{member} \]

Here, `member` can be either a method or an instance variable.

This 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. `super` can also be used to call methods that are hidden by a subclass.
Project 7-1 Extending the Vehicle Class

To illustrate the power of inheritance, we will extend the Vehicle class first developed in Module 4. As you should recall, Vehicle encapsulates information about vehicles, including the number of passengers they can carry, their fuel capacity, and fuel consumption rate. We can use the Vehicle class as a starting point from which more specialized classes are developed. For example, one type of vehicle is a truck. An important attribute of a truck is its cargo capacity. Thus, to create a Truck class, you can extend Vehicle, adding an instance variable that stores the carrying capacity. Here is a version of Vehicle that does this. In the process, the instance variables in Vehicle will be made private, and accessor methods are provided to get and set their values.

Step by Step

1. Create a file called TruckDemo.java and copy the last implementation of Vehicle from Module 4 into the file.

2. Create the Truck class as shown here.

```java
// Extend Vehicle to create a Truck specialization.
class Truck extends Vehicle {
    private int cargocap; // cargo capacity in pounds

    // This is a constructor for Truck.
    Truck(int p, int f, int m, int c) {
        /* Initialize Vehicle members using Vehicle's constructor. */
        super(p, f, m);
        cargocap = c;
    }

    // Accessor methods for cargocap.
    int getCargo() { return cargocap; }
    void putCargo(int c) { cargocap = c; }
}
```

Here, Truck inherits Vehicle, adding cargocap, getCargo(), and putCargo(). Thus, Truck includes all of the general vehicle attributes defined by Vehicle. It need add only those items that are unique to its own class.

(continued)
3. Next, make the instance variables of \texttt{Vehicle} private, as shown here.

\begin{verbatim}
private int passengers; // number of passengers
private int fuelcap;   // fuel capacity in gallons
private int mpg;       // fuel consumption in miles per gallon
\end{verbatim}

4. Here is an entire program that demonstrates the \texttt{Truck} class.

\begin{verbatim}
// Build a subclass of Vehicle for trucks.
class Vehicle {
  private int passengers; // number of passengers
  private int fuelcap;    // fuel capacity in gallons
  private int mpg;        // fuel consumption in miles per gallon

  // This is a constructor for Vehicle.
  Vehicle(int p, int f, int m) {
    passengers = p;
    fuelcap = f;
    mpg = m;
  }

  // Return the range.
  int range() {
    return mpg * fuelcap;
  }

  // Compute fuel needed for a given distance.
  double fuelneeded(int miles) {
    return (double) miles / mpg;
  }

  // Access methods for instance variables.
  int getPassengers() { return passengers; }
  void setPassengers(int p) { passengers = p; }
  int getFuelcap() { return fuelcap; }
  void setFuelcap(int f) { fuelcap = f; }
  int getMpg() { return mpg; }
  void setMpg(int m) { mpg = m; }
}

// Extend Vehicle to create a Truck specialization.
class Truck extends Vehicle {
  private int cargocap; // cargo capacity in pounds

  // This is a constructor for Truck.
  Truck(int p, int f, int m, int c) {
\end{verbatim}
/* Initialize Vehicle members using Vehicle's constructor. */
super(p, f, m);
cargocap = c;
}

// Accessor methods for cargocap.
int getCargo() { return cargocap; }
void putCargo(int c) { cargocap = c; }
}

class TruckDemo {
public static void main(String args[]) {

    // construct some trucks
    Truck semi = new Truck(2, 200, 7, 44000);
    Truck pickup = new Truck(3, 28, 15, 2000);
    double gallons;
    int dist = 252;

    gallons = semi.fuelneeded(dist);
    System.out.println("Semi can carry " + semi.getCargo() + " pounds.");
    System.out.println("To go " + dist + " miles semi needs " + 
gallons + " gallons of fuel.\n");

    gallons = pickup.fuelneeded(dist);
    System.out.println("Pickup can carry " + pickup.getCargo() + " pounds.");
    System.out.println("To go " + dist + " miles pickup needs " + 
gallons + " gallons of fuel.");
}
}

5. The output from this program is shown here:

    Semi can carry 44000 pounds.
    To go 252 miles semi needs 36.0 gallons of fuel.

    Pickup can carry 2000 pounds.
    To go 252 miles pickup needs 16.8 gallons of fuel.

(continued)
6. Many other types of classes can be derived from Vehicle. For example, the following skeleton creates an off-road class that stores the ground clearance of the vehicle.

    // Create an off-road vehicle class
    class OffRoad extends Vehicle {
        private int groundClearance; // ground clearance in inches

        // ...
    }

The key point is that 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.

**Critical Skill 7.4**

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 Triangle is used as a superclass to create the subclass called ColorTriangle. ColorTriangle inherits all of the traits of Triangle and TwoDShape and adds a field called color, which holds the color of the triangle.

    // A multilevel hierarchy.
    class TwoDShape {
        private double width;
        private double height;

        // A default constructor.
        TwoDShape() {
            width = height = 0.0;
        }

        // Parameterized constructor.
        TwoDShape(double w, double h) {
            width = w;
            height = h;
        }
    }
// Construct object with equal width and height.
TwoDShape(double x) {
    width = height = x;
}

// Accessor methods for width and height.
double getWidth() { return width; }
double getHeight() { return height; }
void setWidth(double w) { width = w; }
void setHeight(double h) { height = h; }

void showDim() {
    System.out.println("Width and height are \" +
            width + \" and \" + height);
}
}

// Extend TwoDShape.
class Triangle extends TwoDShape {
    private String style;

    // A default constructor.
    Triangle() {
        super();
        style = "null";
    }

    Triangle(String s, double w, double h) {
        super(w, h); // call superclass constructor
        style = s;
    }

    // Construct an isosceles triangle.
    Triangle(double x) {
        super(x); // call superclass constructor
        style = "isosceles";
    }

    double area() {
        return getWidth() * getHeight() / 2;
    }
}
void showStyle() {
    System.out.println("Triangle is " + style);
}

// Extend Triangle.
class ColorTriangle extends Triangle {
    private String color;

    ColorTriangle(String c, String s,
        double w, double h) {
        super(s, w, h);
        color = c;
    }

    String getColor() { return color; }

    void showColor() {
        System.out.println("Color is " + color);
    }
}

class Shapes6 {
    public static void main(String args[]) {
        ColorTriangle t1 = 
            new ColorTriangle("Blue", "right", 8.0, 12.0);
        ColorTriangle t2 = 
            new ColorTriangle("Red", "isosceles", 2.0, 2.0);

        System.out.println("Info for t1: ");
t1.showStyle();
t1.showDim();
t1.showColor();
System.out.println("Area is " + t1.area());

        System.out.println();

        System.out.println("Info for t2: ");
t2.showStyle();
t2.showDim();
t2.showColor();
System.out.println("Area is " + t2.area());
    }
}
The output of this program is shown here:

```
Info for t1:
Triangle is right
Width and height are 8.0 and 12.0
Color is Blue
Area is 48.0

Info for t2:
Triangle is isosceles
Width and height are 2.0 and 2.0
Color is Red
Area is 2.0
```

Because of inheritance, `ColorTriangle` can make use of the previously defined classes of `Triangle` and `TwoDShape`, 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 `ColorTriangle` calls the constructor in `Triangle`. The `super()` in `Triangle` calls the constructor in `TwoDShape`. 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.

---

**CRITICAL SKILL 7.5 When Are Constructors Called?**

In the foregoing discussion of inheritance and class hierarchies, an important question may have occurred to you: When a subclass object is created, whose constructor is executed first, the one in the subclass or the one defined by the superclass? For example, given a subclass called `B` and a superclass called `A`, is `A`’s constructor called before `B`’s, or vice versa? The answer is that in a class hierarchy, constructors are called 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 (parameterless) constructor of each superclass will be executed. The following program illustrates when constructors are executed:

```
// Demonstrate when constructors are called.

// Create a super class.
class A {
    A() {
        System.out.println("Constructing A.");
    }
}
```
// Create a subclass by extending class A.
class B extends A {
    B() {
        System.out.println("Constructing B.");
    }
}

// Create another subclass by extending B.
class C extends B {
    C() {
        System.out.println("Constructing C.");
    }
}

class OrderOfConstruction {
    public static void main(String args[]) {
        C c = new C();
    }
}

The output from this program is shown here:

Constructing A.
Constructing B.
Constructing C.

As you can see, the constructors are called in order of derivation.

If you think about it, it makes sense that constructor functions are executed 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 be executed first.

CRITICAL SKILL

Superclass References and Subclass Objects

As you know, Java is a strongly typed language. Aside from the standard conversions and automatic promotions that apply to its simple types, type compatibility is strictly enforced. Therefore, a reference variable for one class type cannot normally refer to an object of another class type. For example, consider the following program.

// This will not compile.
class X {
    int a;
Inheritance

X(int i) { a = i; }
}

class Y {
    int a;

    Y(int i) { a = i; }
}

class IncompatibleRef {
    public static void main(String args[]) {
        X x = new X(10);
        X x2;
        Y y = new Y(5);

        x2 = x; // OK, both of same type

        x2 = y; // Error, not of same type
    }
}

Here, even though class X and class Y are physically the same, it is not possible to assign an X reference to a Y object because they have different types. In general, an object reference variable can refer only to objects of its type.

There is, however, an important exception to Java’s strict type enforcement. A reference variable of a superclass can be assigned a reference to any subclass derived from that superclass. Here is an example:

// A superclass reference can refer to a subclass object.
class X {
    int a;

    X(int i) { a = i; }
}

class Y extends X {
    int b;

    Y(int i, int j) {
        super(j);
        b = i;
    }
}
class SupSubRef {
    public static void main(String args[]) {
        X x = new X(10);
        X x2;
        Y y = new Y(5, 6);

        x2 = x; // OK, both of same type
        System.out.println("x2.a: " + x2.a);

        x2 = y; // still Ok because Y is derived from X
        System.out.println("x2.a: " + x2.a);

        // X references know only about X members
        x2.a = 19; // OK
        // x2.b = 27; // Error, X doesn't have a b member
    }
}

Here, Y is now derived from X; thus it is permissible for x2 to be assigned a reference to a Y 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 x2 can't access b even when it
    refers to a Y 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 program is
    commented out.

    Although the preceding discussion may seem a bit esoteric, it has some important practical
    applications. One is described here. The other is discussed later in this module, when method
    overriding is covered.

    An important place where subclass references are assigned to superclass variables is when
    constructors are called in a class hierarchy. As you know, it is common for a class to define
    a constructor that takes an object of the class as a parameter. This allows the class to construct a
    copy of an object. Subclasses of such a class can take advantage of this feature. For example,
    consider the following versions of TwoDShape and Triangle. Both add constructors that take
    an object as a parameter.

    class TwoDShape {
        private double width;
        private double height;
    }
// A default constructor.
TwoDShape() {
    width = height = 0.0;
}

// Parameterized constructor.
TwoDShape(double w, double h) {
    width = w;
    height = h;
}

// Construct object with equal width and height.
TwoDShape(double x) {
    width = height = x;
}

// Construct an object from an object.
TwoDShape(TwoDShape ob) {
    width = ob.width;
    height = ob.height;
}

// Accessor methods for width and height.
double getWidth() { return width; }  
double getHeight() { return height; }
void setWidth(double w) { width = w; }
void setHeight(double h) { height = h; }

void showDim() {
    System.out.println("Width and height are " +
                     width + " and " + height);
}

// A subclass of TwoDShape for triangles.
class Triangle extends TwoDShape {
    private String style;

    // A default constructor.
    Triangle() {
        super();
        style = "null";
    }

    // Construct object from an object.
    Triangle(TwoDShape ob) {
        super(ob);
        style = ob.style;
    }

    // Accessor methods for width and height.
    double getWidth() { return width; }  
double getHeight() { return height; }
void setWidth(double w) { width = w; }
void setHeight(double h) { height = h; }

    // Additional methods for Triangle
    //...
}

// Constructor for Triangle.
Triangle(String s, double w, double h) {
    super(w, h); // call superclass constructor
    style = s;
}

// Construct an isosceles triangle.
Triangle(double x) {
    super(x); // call superclass constructor
    style = "isosceles";
}

// Construct an object from an object.
Triangle(Triangle ob) {
    super(ob); // pass object to TwoDShape constructor
    style = ob.style;
}

double area() {
    return getWidth() * getHeight() / 2;
}

void showStyle() {
    System.out.println("Triangle is "+style);
}

class Shapes7 {
    public static void main(String args[]) {
        Triangle t1 =
        new Triangle("right", 8.0, 12.0);

        // make a copy of t1
        Triangle t2 = new Triangle(t1);

        System.out.println("Info for t1: ");
        t1.showStyle();
        t1.showDim();
        t1.showDim();
        System.out.println("Area is " + t1.area());

        System.out.println();
In this program, \texttt{t2} is constructed from \texttt{t1} and is, thus, identical. The output is shown here.

\begin{verbatim}
Info for t1:
Triangle is right
Width and height are 8.0 and 12.0
Area is 48.0

Info for t2:
Triangle is right
Width and height are 8.0 and 12.0
Area is 48.0
\end{verbatim}

Pay special attention to this \texttt{Triangle} constructor:

\begin{verbatim}
// Construct an object from an object.
Triangle(Triangle ob) {
    super(ob); // pass object to TwoDShape constructor
    style = ob.style;
}
\end{verbatim}

It receives an object of type \texttt{Triangle} and it passes that object (through \texttt{super}) to this \texttt{TwoDShape} constructor:

\begin{verbatim}
// Construct an object from an object.
TwoDShape(TwoDShape ob) {
    width = ob.width;
    height = ob.height;
}
\end{verbatim}

The key point is that \texttt{TwoDshape()} is expecting a \texttt{TwoDShape} object. However, \texttt{Triangle()} passes it a \texttt{Triangle} object. The reason this works is because, as explained, a superclass reference can refer to a subclass object. Thus it is perfectly acceptable to pass \texttt{TwoDShape()} a reference to an object of a class derived from \texttt{TwoDShape}. Because the \texttt{TwoDShape()} constructor is initializing only those portions of the subclass object that are members of \texttt{TwoDShape}, it doesn’t matter that the object might also contain other members added by derived classes.
Progress Check

1. Can a subclass be used as a superclass for another subclass?

2. In a class hierarchy, in what order are the constructors called?

3. Given that Jet extends Airplane, can an Airplane reference refer to a Jet object?

CRITICAL SKILL 7.7 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 a 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;
    }
}
```

1. Yes.
2. Constructors are called in order of derivation.
3. Yes. In all cases, a superclass reference can refer to a subclass object, but not vice versa.
Inheritance

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:

k: 3

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 want 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.

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 show() 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:

```java
/* Methods with differing type signatures are overloaded and 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 Overload {
    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
    }
}
```

Because signatures differ, this `show()` simply overloads `show()` in superclass `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.

---

**CRITICAL SKILL 7.8  Overridden Methods Support Polymorphism**

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’s 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:

```java
// Demonstrate dynamic method dispatch.

class Sup {
    void who() {
        System.out.println("who() in Sup");
    }
}
```
class Sub1 extends Sup {
    void who() {
        System.out.println("who() in Sub1");
    }
}

class Sub2 extends Sup {
    void who() {
        System.out.println("who() in Sub2");
    }
}

class DynDispDemo {
    public static void main(String args[]) {
        Sup superOb = new Sup();
        Sub1 subOb1 = new Sub1();
        Sub2 subOb2 = new Sub2();

        Sup supRef;

        supRef = superOb;
        supRef.who();

        supRef = subOb1;
        supRef.who();

        supRef = subOb2;
        supRef.who();
    }
}

The output from the program is shown here:

who() in Sup
who() in Sub1
who() in Sub2

This program creates a superclass called Sup and two subclasses of it, called Sub1 and Sub2. Sup declares a method called who(), and the subclasses override it. Inside the main() method, objects of type Sup, Sub1, and Sub2 are declared. Also, a reference of type Sup, called supRef, is declared. The program then assigns a reference to each type of object to supRef and uses that reference to call who(). As the output shows, the version of who() executed is determined by the type of object being referred to at the time of the call, not by the class type of supRef.
**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 that 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.

**Applying Method Overriding to TwoDShape**

To better understand the power of method overriding, we will apply it to the TwoDShape class. In the preceding examples, each class derived from TwoDShape defines a method called area(). This suggests that it might be better to make area() part of the TwoDShape class, allowing each subclass to override it, defining how the area is calculated for the type of shape that the class encapsulates. The following program does this. For convenience, it also adds a name field to TwoDShape. (This makes it easier to write demonstration programs.)

```java
// Use dynamic method dispatch.
class TwoDShape {
    private double width;
    private double height;
    private String name;
```
/ A default constructor.
TwoDShape() {
    width = height = 0.0;
    name = "null";
}

// Parameterized constructor.
TwoDShape(double w, double h, String n) {
    width = w;
    height = h;
    name = n;
}

// Construct object with equal width and height.
TwoDShape(double x, String n) {
    width = height = x;
    name = n;
}

// Construct an object from an object.
TwoDShape(TwoDShape ob) {
    width = ob.width;
    height = ob.height;
    name = ob.name;
}

// Accessor methods for width and height.
double getWidth() { return width; }
double getHeight() { return height; }
void setWidth(double w) { width = w; }
void setHeight(double h) { height = h; }

String getName() { return name; }

void showDim() {
    System.out.println("Width and height are " +
    width + " and " + height);
}

The area() method defined by TwoDShape.

double area() {
    System.out.println("area() must be overridden");
    return 0.0;
}
// A subclass of TwoDShape for triangles.
class Triangle extends TwoDShape {
    private String style;

    // A default constructor.
    Triangle() {
        super();
        style = "null";
    }

    // Constructor for Triangle.
    Triangle(String s, double w, double h) {
        super(w, h, "triangle");
        style = s;
    }

    // Construct an isosceles triangle.
    Triangle(double x) {
        super(x, "triangle"); // call superclass constructor
        style = "isosceles";
    }

    // Construct an object from an object.
    Triangle(Triangle ob) {
        super(ob); // pass object to TwoDShape constructor
        style = ob.style;
    }

    // Override area() for Triangle.
    double area() {
        return getWidth() * getHeight() / 2;
    }

    void showStyle() {
        System.out.println("Triangle is "+ style);
    }
}

// A subclass of TwoDShape for rectangles.
class Rectangle extends TwoDShape {
    // A default constructor.
    Rectangle() {
        super();
    }
// Constructor for Rectangle.
Rectangle(double w, double h) {
    super(w, h, "rectangle"); // call superclass constructor
}

// Construct a square.
Rectangle(double x) {
    super(x, "rectangle"); // call superclass constructor
}

// Construct an object from an object.
Rectangle(Rectangle ob) {
    super(ob); // pass object to TwoDShape constructor
}

boolean isSquare() {
    if(getWidth() == getHeight()) return true;
    return false;
}

// Override area() for Rectangle.
double area() {
    return getWidth() * getHeight();
}
}

class DynShapes {
    public static void main(String args[]) {
        TwoDShape shapes[] = new TwoDShape[5];

        shapes[0] = new Triangle("right", 8.0, 12.0);
        shapes[1] = new Rectangle(10);
        shapes[2] = new Rectangle(10, 4);
        shapes[3] = new Triangle(7.0);
        shapes[4] = new TwoDShape(10, 20, "generic");

        for(int i=0; i < shapes.length; i++) {
            System.out.println("object is " + shapes[i].getName());
            System.out.println("Area is " + shapes[i].area());
        }
    }
}
System.out.println();
}
}
}

The output from the program is shown here:

object is triangle
Area is 48.0

object is rectangle
Area is 100.0

object is rectangle
Area is 40.0

object is triangle
Area is 24.5

object is generic
area() must be overridden
Area is 0.0

Let’s examine this program closely. First, as explained, area() is now part of the TwoDShape class and is overridden by Triangle and Rectangle. Inside TwoDShape, area() is given a placeholder implementation that simply informs the user that this method must be overridden by a subclass. Each override of area() supplies an implementation that is suitable for the type of object encapsulated by the subclass. Thus, if you were to implement an ellipse class, for example, then area() would need to compute the area() of an ellipse.

There is one other important feature in the preceding program. Notice in main() that shapes is declared as an array of TwoDShape objects. However, the elements of this array are assigned Triangle, Rectangle, and TwoDShape references. This is valid because, as explained, a superclass reference can refer to a subclass object. The program then cycles through the array, displaying information about each object. Although quite simple, this illustrates the power of both inheritance and method overriding. The type of object referred to by a superclass reference variable is determined at run time and acted on accordingly. If an object is derived from TwoDShape, then its area can be obtained by calling area(). The interface to this operation is the same no matter what type of shape is being used.
Progress Check

1. What is method overriding?

2. Why is method overriding important?

3. When an overridden method is called through a superclass reference, which version of the method is executed?

Critical Skill

Using Abstract Classes

Sometimes you will want to create a superclass that defines only 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 but does not, itself, provide an implementation of one or more of these methods. 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 version of TwoDShape 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 which 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.

An abstract method is created by specifying the abstract type modifier. An abstract method contains no body and is, therefore, not implemented by the superclass. Thus, a subclass must override it—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. The abstract modifier can be used only on normal methods. It cannot be applied to static methods or to constructors.

1. Method overriding occurs when a subclass defines a method that has the same signature as a method in its superclass.
2. Overridden methods allow Java to support run-time polymorphism.
3. The version of an overridden method that is executed is determined by the type of the object being referred to at the time of the call. Thus, this determination is made at run time.
A class that contains one or more abstract methods must also be declared as abstract by preceding its `class` declaration with the `abstract` specifier. Since an abstract class does not define a complete implementation, there can be no objects of an abstract class. Thus, attempting to create an object of an abstract class by using `new` will result in a compile-time error.

When a subclass inherits an abstract class, it must implement all of the abstract methods in the superclass. If it doesn’t, then the subclass must also be specified as `abstract`. Thus, the `abstract` attribute is inherited until such time as a complete implementation is achieved.

Using an abstract class, you can improve the `TwoDShape` class. Since there is no meaningful concept of area for an undefined two-dimensional figure, the following version of the preceding program declares `area()` as `abstract` inside `TwoDShape`, and `TwoDShape` as `abstract`. This, of course, means that all classes derived from `TwoDShape` must override `area()`.

```java
// Create an abstract class.
abstract class TwoDShape {  // TwoDShape is now abstract.
    private double width;
    private double height;
    private String name;

    // A default constructor.
    TwoDShape() {
        width = height = 0.0;
        name = "null";
    }

    // Parameterized constructor.
    TwoDShape(double w, double h, String n) {
        width = w;
        height = h;
        name = n;
    }

    // Construct object with equal width and height.
    TwoDShape(double x, String n) {
        width = height = x;
        name = n;
    }

    // Construct an object from an object.
    TwoDShape(TwoDShape ob) {
        width = ob.width;
        height = ob.height;
        name = ob.name;
    }
```
// Accessor methods for width and height.
double getWidth() { return width; }
double getHeight() { return height; }
void setWidth(double w) { width = w; }
void setHeight(double h) { height = h; }

String getName() { return name; }

void showDim() {
    System.out.println("Width and height are " +
            width + " and " + height);
}

// Now, area() is abstract.
abstract double area();

// A subclass of TwoDShape for triangles.
class Triangle extends TwoDShape {
    private String style;

    // A default constructor.
    Triangle() {
        super();
        style = "null";
    }

    // Constructor for Triangle.
    Triangle(String s, double w, double h) {
        super(w, h, "triangle");

        style = s;
    }

    // Construct an isosceles triangle.
    Triangle(double x) {
        super(x, "triangle"); // call superclass constructor

        style = "isosceles";
    }

    // Construct an object from an object.
    Triangle(Triangle ob) {
        super(ob); // pass object to TwoDShape constructor
        style = ob.style;
    }
}
double area() {
    return getWidth() * getHeight() / 2;
}

void showStyle() {
    System.out.println("Triangle is "+style);
}
}

// A subclass of TwoDShape for rectangles.
class Rectangle extends TwoDShape {
    // A default constructor.
    Rectangle() {
        super();
    }

    // Constructor for Rectangle.
    Rectangle(double w, double h) {
        super(w, h, "rectangle"); // call superclass constructor
    }

    // Construct a square.
    Rectangle(double x) {
        super(x, "rectangle"); // call superclass constructor
    }

    // Construct an object from an object.
    Rectangle(Rectangle ob) {
        super(ob); // pass object to TwoDShape constructor
    }

    boolean isSquare() {
        if(getWidth() == getHeight()) return true;
        return false;
    }

    double area() {
        return getWidth() * getHeight();
    }
}

class AbsShape {
    public static void main(String args[]) {
        TwoDShape shapes[] = new TwoDShape[4];
shapes[0] = new Triangle("right", 8.0, 12.0);
shapes[1] = new Rectangle(10);
shapes[2] = new Rectangle(10, 4);
shapes[3] = new Triangle(7.0);

for(int i=0; i < shapes.length; i++) {
    System.out.println("object is " +
        shapes[i].getName());
    System.out.println("Area is " + shapes[i].area());
}

As the program illustrates, all subclasses of TwoDShape must override area().
To prove this to yourself, try creating a subclass that does not override area(). You will receive a compile-time error. Of course, it is still possible to create an object reference of type TwoDShape, which the program does. However, it is no longer possible to declare objects of type TwoDShape. Because of this, in main() the shapes array has been shortened to 4, and a generic TwoDShape object is no longer created.

One last point: notice that TwoDShape still includes the showDim() and getName() methods and that these are not modified by abstract. It is perfectly acceptable—indeed, quite common—for an abstract class to contain concrete methods which a subclass is free to use as is. Only those methods declared as abstract need be overridden by subclasses.

Progress Check

1. What is an abstract method? How is one created?
2. What is an abstract class?
3. Can an object of an abstract class be instantiated?

1. An abstract method is a method without a body. Thus it consists of a return type, name, and parameter list and is preceded by the keyword abstract.
2. An abstract class contains at least one abstract method.
3. No.
CRITICAL SKILL

7.10 Using final

As powerful and useful as method overriding and inheritance are, sometimes you will want to prevent them. For example, you might have a class that encapsulates control of some hardware device. Further, this class might offer the user the ability to initialize the device, making use of private, proprietary information. In this case, you don’t want users of your class to be able to override the initialization method. Whatever the reason, in Java it is easy to prevent a method from being overridden or a class from being inherited by using the keyword final.

final Prevents Overriding

To prevent 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.

final Prevents Inheritance

You can prevent a class from being inherited by preceding its 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:

```java
final class A {
    // ...
}
```
// The following class is illegal.
class B extends A { // ERROR! Can't subclass A
    // ...
}

As the comments imply, it is illegal for B to inherit A since A is declared as final.

Using final with Data Members

In addition to the uses of final just shown, final can also be applied to variables to create what amounts to named constants. If you precede a class variable’s name with final, its value cannot be changed through the lifetime of your program. You can, of course, give that variable an initial value. For example, in Module 6 a simple error-management class called ErrorMsg was shown. That class mapped a human-readable string to an error code. Here, that original class is improved by the addition of final constants which stand for the errors. Now, instead of passing getErrorMsg() a number such as 2, you can pass the named integer constant DISKERR.

// Return a String object.
class ErrorMsg {
    // Error codes.
    final int OUTERR   = 0;
    final int INERR    = 1;
    final int DISKERR  = 2;
    final int INDEXERR = 3;

    String msgs[] = {
        "Output Error",
        "Input Error",
        "Disk Full",
        "Index Out-Of-Bounds"
    };

    // Return the error message.
    String getErrorMsg(int i) {
        if(i >=0 & i < msgs.length)
            return msgs[i];
        else
            return "Invalid Error Code";
    }
}
class FinalD {
    public static void main(String args[]) {
        ErrorMsg err = new ErrorMsg();
        System.out.println(err.getErrorMsg(err.OUTERR));
        System.out.println(err.getErrorMsg(err.DISKERR));
    }
}

Notice how the final constants are used in main(). Since they are members of the ErrorMsg class, they must be accessed via an object of that class. Of course, they can also be inherited by subclasses and accessed directly inside those subclasses.

As a point of style, many Java programmers use uppercase identifiers for final constants, as does the preceding example. But this is not a hard and fast rule.

Ask the Expert

Q: Can final variables be made static?

A: Yes. Doing so allows you to refer to the constant through its class name rather than through an object. For example, if the constants in ErrorMsg were modified by static, then the println() statements in main() could look like this:

        System.out.println(err.getErrorMsg(ErrorMsg.OUTERR));
        System.out.println(err.getErrorMsg(ErrorMsg.DISKERR));

Progress Check

1. How do you prevent a method from being overridden?

2. If a class is declared as final, can it be inherited?

1. Precede its declaration with the keyword final.
2. No.
Java defines one special class called Object that is an implicit superclass of all other classes. In other words, all other classes are subclasses of Object. 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.</td>
</tr>
<tr>
<td>Class 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, int nanoseconds)</td>
<td></td>
</tr>
</tbody>
</table>

The methods getClass( ), notify( ), notifyAll( ), and wait( ) are declared as final. You can override the others. Several of these methods are described later in this book. However, notice two methods now: equals( ) and toString( ). The equals( ) method compares the contents of two objects. It returns true if the objects are equivalent, and false otherwise. 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.
Module 7 Mastery Check

1. Does a superclass have access to the members of a subclass? Does a subclass have access to the members of a superclass?

2. Create a subclass of \texttt{TwoDShape} called \texttt{Circle}. Include an \texttt{area()} method that computes the area of the circle and a constructor that uses \texttt{super} to initialize the \texttt{TwoDShape} portion.

3. How do you prevent a subclass from having access to a member of a superclass?

4. Describe the purpose and use of both versions of \texttt{super}.

5. Given the following hierarchy:

   \begin{verbatim}
   class Alpha { ... \\
   class Beta extends Alpha { ... \\
   Class Gamma extends Beta { ... \\
   
   In what order are the constructors for these classes called when a \texttt{Gamma} object is instantiated?
   \end{verbatim}

6. A superclass reference can refer to a subclass object. Explain why this is important as it relates to method overriding.

7. What is an abstract class?

8. How do you prevent a method from being overridden? How do you prevent a class from being inherited?

9. Explain how inheritance, method overriding, and abstract classes are used to support polymorphism.

10. What class is a superclass of every other class?

11. A class that contains at least one abstract method must, itself, be declared abstract. True or False?

12. What keyword is used to create a named constant?
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Module 8

Packages and Interfaces

CRITICAL SKILLS

8.1 Use packages
8.2 Understand how packages affect access
8.3 Apply the protected access specifier
8.4 Import packages
8.5 Know Java’s standard packages
8.6 Understand interface fundamentals
8.7 Implement an interface
8.8 Apply interface references
8.9 Understand interface variables
8.10 Extend interfaces
This module examines two of Java’s most innovative features: packages and interfaces. Packages are groups of related classes. Packages help organize your code and provide another layer of encapsulation. An interface defines a set of methods that will be implemented by a class. An interface does not, itself, implement any method. It is a purely logical construct. Packages and interfaces give you greater control over the organization of your program.

**CRITICAL SKILL 8.1 Packages**

In programming, it is often helpful to group related pieces of a program together. In Java, this is accomplished by using a package. A package serves two purposes. First, it provides a mechanism by which related pieces of a program can be organized as a unit. Classes defined within a package must be accessed through their package name. Thus, a package provides a way to name a collection of classes. Second, a package participates in Java’s access control mechanism. Classes defined within a package can be made private to that package and not accessible by code outside the package. Thus, the package provides a means by which classes can be encapsulated. Let’s examine each feature a bit more closely.

In general, when you name a class, you are allocating a name from the namespace. A namespace defines a declarative region. In Java, no two classes can use the same name from the same namespace. Thus, within a given namespace, each class name must be unique. The examples shown in the preceding modules have all used the default or global namespace. While this is fine for short sample programs, it becomes a problem as programs grow and the default namespace becomes crowded. In large programs, finding unique names for each class can be difficult. Furthermore, you must avoid name collisions with code created by other programmers working on the same project, and with Java’s library. The solution to these problems is the package because it gives you a way to partition the namespace. When a class is defined within a package, the name of that package is attached to each class, thus avoiding name collisions with other classes that have the same name, but are in other packages.

Since a package usually contains related classes, Java defines special access rights to code within a package. In a package, you can define code that is accessible by other code within the same package but not by code outside the package. This enables you to create self-contained groups of related classes that keep their operation private.

**Defining a Package**

All classes in Java belong to some package. When no `package` statement is specified, the default (or global) package is used. Furthermore, the default package has no name, which makes the default package transparent. 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 one or more packages for your code.

To create a package, put a `package` command at the top of a Java source file. The classes declared within that file will then belong to the specified package. Since a package defines a namespace, the names of the classes that you put into the file become part of that package’s namespace.

This is the general form of the `package` statement:

```java
package pkg;
```

Here, `pkg` is the name of the package. For example, the following statement creates a package called `Project1`.

```java
package Project1;
```

Java uses the file system to manage packages, with each package stored in its own directory. For example, the `.class` files for any classes you declare to be part of `Project1` must be stored in a directory called `Project1`.

Like the rest of Java, package names are case sensitive. This means that the directory in which a package is stored must be precisely the same as the package name. If you have trouble trying the examples in this module, remember to check your package and directory names carefully.

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:

```java
package pack1.pack2.pack3...packN;
```

Of course, you must create directories that support the package hierarchy that you create. For example,

```java
package X.Y.Z;
```

must be stored in `.../X/Y/Z`, where `...` specifies the path to the specified directories.
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? The answer has two parts. First, by default, the Java run-time system uses the current working directory as its starting point. Thus, if your class files are in the current directory, or a subdirectory of the current directory, they will be found. Second, you can specify a directory path or paths by setting the CLASSPATH environmental variable.

For example, consider the following package specification.

```java
package MyPack;
```

In order for a program to find MyPack, one of two things must be true. Either the program is executed from a directory immediately above MyPack, or CLASSPATH must be set to include the path to MyPack. The first alternative is the easiest (and doesn’t require a change to CLASSPATH), but the second alternative lets your program find MyPack no matter what directory the program is in. Ultimately, the choice is yours.

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 assumed by the examples.

One last point: To avoid confusion, it is best to keep all .java and .class files associated with packages in their own package directories.

**NOTE**

The precise effect and setting of CLASSPATH has changed over time, with each revision of Java. It is best to check Sun’s Web site java.sun.com for the latest information.

A Short Package Example

Keeping the preceding discussion in mind, try this short package example. It creates a simple book database that is contained within a package called BookPack.

```java
// A short package demonstration.
package BookPack;  // This file is part of the BookPack package.

class Book {  // Thus, Book is part of BookPack.
    private String title;
    private String author;
    private int pubDate;

    Book(String t, String a, int d) {
```
Call this file BookDemo.java and put it in a directory called BookPack.

Next, compile the file. Make sure that the resulting .class file is also in the BookPack directory. Then try executing the class, using the following command line:

```
java BookPack.BookDemo
```

Remember, you will need to be in the directory above BookPack when you execute this command or have your CLASSPATH environmental variable set appropriately.

As explained, BookDemo and Book are now part of the package BookPack. This means that BookDemo cannot be executed by itself. That is, you cannot use this command line:

```
java BookDemo
```

Instead, BookDemo must be qualified with its package name.
Progress Check

1. What is a package?

2. Show how to declare a package called ToolPack.

3. What is CLASSPATH?

Critical Skill 8.2 Packages and Member Access

The preceding modules have introduced the fundamentals of access control, including the private and public specifiers, but they have not told the entire story. The reason for this is that packages also participate in Java's access control mechanism, and a complete discussion had to wait until packages were covered.

The visibility of an element is determined by its access specification—private, public, protected, or default—and the package in which it resides. Thus, the visibility of an element is determined by its visibility within a class and its visibility within a package. This multilayered approach to access control supports a rich assortment of access privileges. Table 8-1 summarizes the various access levels. Let's examine each access option individually.

If a member of a class has no explicit access specifier, then it is visible within its package but not outside its package. Therefore, you will use the default access specification for elements that you want to keep private to a package but public within that package.

Members explicitly declared public are visible everywhere, including different classes and different packages. There is no restriction on their use or access.

A private member is accessible only to the other members of its class. A private member is unaffected by its membership in a package.

A member specified as protected is accessible within its package and to all subclasses, including subpackages in other packages.

Table 8-1 applies only to members of classes. A class has only two possible access levels: default and public. When a class is declared as public, it is accessible by any other code. If a class has default access, it can be accessed only by other code within its same package. Also, a class that is declared public must reside in a file by the same name.

1. A package is a container for classes. It performs both an organization and an encapsulation role.
2. package ToolPack;
3. CLASSPATH is the environmental variable that specifies the path to classes.
Progress Check

1. If a class member has default access inside a package, is that member accessible by other packages?
2. What does protected do?
3. A private member can be accessed by subclasses within its packages. True or False?

A Package Access Example

In the package example shown earlier, both Book and BookDemo were in the same package, so there was no problem with BookDemo using Book because the default access privilege grants all members of the same package access. However, if Book were in one package and...
BookDemo were in another, the situation would be different. In this case, access to Book would be denied. To make Book available to other packages, you must make three changes. First, Book needs to be declared public. This makes Book visible outside of BookPack. Second, its constructor must be made public, and finally its show() method needs to be public. This allows them to be visible outside of BookPack, too. Thus, to make Book usable by other packages, it must be recoded as shown here.

// Book recoded for public access.
package BookPack;

public class Book { ←Book and its members must be public in order to be used by other packages.
    private String title;
    private String author;
    private int pubDate;

    // Now public.
    public Book(String t, String a, int d) {
        title = t;
        author = a;
        pubDate = d;
    }

    // Now public.
    public void show() {
        System.out.println(title);
        System.out.println(author);
        System.out.println(pubDate);
        System.out.println();
    }
}

To use Book from another package, either you must use the import statement described in the next section, or you must fully qualify its name to include its full package specification. For example, here is a class called UseBook, which is contained in the BookPackB package. It fully qualifies Book in order to use it.

// This class is in package BookPackB.
package BookPackB;

// Use the Book Class from BookPack.
class UseBook {
    public static void main(String args[]) {
    }
}

for(int i=0; i < books.length; i++) books[i].show();
}
}

Notice how every use of Book is preceded with the BookPack qualifier. Without this specification, Book would not be found when you tried to compile UseBook.

### Critical Skill

#### 8.3 Understanding Protected Members

Newcomers to Java are sometimes confused by the meaning and use of protected. As explained, the protected specifier creates a member that is accessible within its package and to subclasses in other packages. Thus, a protected member is available for all subclasses to use but is still protected from arbitrary access by code outside its package.

To better understand the effects of protected, let’s work through an example. First, change the Book class so that its instance variables are protected, as shown here.

```java
// Make the instance variables in Book protected.
package BookPack;

public class Book {
    // these are now protected
    protected String title;
    protected String author;
    protected int pubDate;

    public Book(String t, String a, int d) {
        title = t;
        author = a;
        pubDate = d;
    }
}
```
Next, create a subclass of Book, called ExtBook, and a class called ProtectDemo that uses ExtBook. ExtBook adds a field that stores the name of the publisher and several accessor methods. Both of these classes will be in their own package called BookPackB. They are shown here.

// Demonstrate Protected.
package BookPackB;

class ExtBook extends BookPack.Book {
    private String publisher;

    public ExtBook(String t, String a, int d, String p) {
        super(t, a, d);
        publisher = p;
    }

    public void show() {
        super.show();
        System.out.println(publisher);
        System.out.println();
    }

    public String getPublisher() { return publisher; }
    public void setPublisher(String p) { publisher = p; }

    /* These are OK because subclass can access
     a protected member. */
    public String getTitle() { return title; }
    public void setTitle(String t) { title = t; }
    public String getAuthor() { return author; }
    public void setAuthor(String a) { author = a; }
    public int getPubDate() { return pubDate; }
    public void setPubDate(int d) { pubDate = d; }
}
class ProtectDemo {
    public static void main(String args[]) {
        ExtBook books[] = new ExtBook[5];

                                "Schildt", 2000, "Osborne/McGraw-Hill");
                                "Powell and Whitworth", 1998,
                                "Osborne/McGraw-Hill");
                                "Clancy", 1986, "Putnam");
                                "Kerouac", 1955, "Viking");

        for(int i=0; i < books.length; i++) books[i].show();
        // Find books by author
        System.out.println("Showing all books by Schildt.");
        for(int i=0; i < books.length; i++)
            if(books[i].getAuthor() == "Schildt")
                System.out.println(books[i].getTitle());
        //    books[0].title = "test title"; // Error -- not accessible
    }

}  // Access to protected field not allowed by non-subclass.

Look first at the code inside ExtBook. Because ExtBook extends Book, it has access
to the protected members of Book even though ExtBook is in a different package. Thus, it
can access title, author, and pubDate directly, as it does in the accessor methods it creates
for those variables. However, in ProtectDemo, access to these variables is denied because
ProtectDemo is not a subclass of Book. For example, if you remove the comment symbol
from the following line, the program will not compile.

    //    books[0].title = "test title"; // Error -- not accessible

CRITICAL SKILL

8.4 Importing Packages

When you use a class from another package, you can fully qualify the name of the class with
the name of its package, as the preceding examples have done. However, such an approach
could easily become tiresome and awkward, especially if the classes you are qualifying are
Module 8: Packages and Interfaces

Ask the Expert

Q: I know that C++ also includes an access specifier called protected. Is it similar to Java’s?

A: Similar, but not the same. In C++, protected creates a member that can be accessed by subclasses but is otherwise private. In Java, protected creates a member that can be accessed by any code within its package but only by subclasses outside of its package. You need to be careful of this difference when porting code between C++ and Java.

deeply nested in a package hierarchy. Since Java was invented by programmers for programmers—and programmers don’t like tedious constructs—it should come as no surprise that a more convenient method exists for using the contents of packages: the import statement. Using import you can bring one or more members of a package into view. This allows you to use those members directly, without explicit package qualification.

Here is the general form of the import statement:

```
import pkg.classname;
```

Here, pkg is the name of the package, which can include its full path, and classname is the name of the class being imported. If you want to import the entire contents of a package, use an asterisk (*) for the class name. Here are examples of both forms:

```
import MyPack.MyClass
import MyPack. *
```

In the first case, the MyClass class is imported from MyPack. In the second, all of the classes in MyPack are imported. In a Java source file, import statements occur immediately following the package statement (if it exists) and before any class definitions.

You can use import to bring the BookPack package into view so that the Book class can be used without qualification. To do so, simply add this import statement to the top of any file that uses Book.

```
import BookPack. *
```
For example, here is the `UseBook` class recoded to use `import`.

```java
// Demonstrate import.
package BookPackB;
import BookPack.*;

// Use the Book Class from BookPack.
class UseBook {
    public static void main(String args[]) {
        Book books[] = new Book[5];
        books[0] = new Book("Java 2: A Beginner's Guide", "Schildt", 2002);

        for(int i=0; i < books.length; i++) books[i].show();
    }
}
```

Notice that you no longer need to qualify `Book` with its package name.

---

**Ask the Expert**

**Q:** Does importing a package have an impact on the performance of my program?

**A:** Yes and no! Importing a package can create a small amount of overhead during compilation, but it has no impact on performance at run time.
Java’s Class Library Is Contained in Packages

As explained earlier in this book, Java defines a large number of standard classes that are available to all programs. This class library is often referred to as the Java API (Application Programming Interface). The Java API is stored in packages. At the top of the package hierarchy is `java`. Descending from `java` are several subpackages, including these:

<table>
<thead>
<tr>
<th>Subpackage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>java.lang</td>
<td>Contains a large number of general-purpose classes</td>
</tr>
<tr>
<td>java.io</td>
<td>Contains the I/O classes</td>
</tr>
<tr>
<td>java.net</td>
<td>Contains those classes that support networking</td>
</tr>
<tr>
<td>java.applet</td>
<td>Contains classes for creating applets</td>
</tr>
<tr>
<td>java.awt</td>
<td>Contains classes that support the Abstract Window Toolkit</td>
</tr>
</tbody>
</table>

Since the beginning of this book, you have been using `java.lang`. It contains, among several others, the `System` class, which you have been using when performing output using `println()`. The `java.lang` package is unique because it is imported automatically into every Java program. This is why you did not have to import `java.lang` in the preceding sample programs. However, you must explicitly import the other packages. We will be examining several packages in subsequent modules.

Progress Check

1. How do you include another package in a source file?
2. Show how to include all of the classes in a package called ToolPack.
3. Do you need to include `java.lang` explicitly?

1. Use the `import` statement.
2. `import ToolPack.*;`
3. No.
In object-oriented programming, it is sometimes helpful to define what a class must do but not how it will do it. You have already seen an example of this: the abstract method. An abstract method defines the signature for a method but provides no implementation. A subclass must provide its own implementation of each abstract method defined by its superclass. Thus, an abstract method specifies the interface to the method but not the implementation. While abstract classes and methods are useful, it is possible to take this concept a step further. In Java, you can fully separate a class’s interface from its implementation by using the keyword interface.

Interfaces are syntactically similar to abstract classes. However, in an interface, no method can include a body. That is, an interface provides no implementation whatsoever. It specifies what must be done, but not how. Once an interface is defined, any number of classes can implement it. Also, one class can implement any number of interfaces.

To implement an interface, a class must provide bodies (implementations) for the methods described by the interface. Each class is free to determine the details of its own implementation. Thus, two classes might implement the same interface in different ways, but each class still supports the same set of methods. Thus, code that has knowledge of the interface can use objects of either class since the interface to those objects is the same. By providing the interface keyword, Java allows you to fully utilize the “one interface, multiple methods” aspect of polymorphism.

Here is the general form of an interface:

```
access interface name {
  ret-type method-name1(param-list);
  ret-type method-name2(param-list);
  type var1 = value;
  type var2 = value;
  // ...
  ret-type method-nameN(param-list);
  type varN = value;
}
```

Here, access is either public or not used. When no access specifier is included, then default access results, and the interface is available only to other members of its package. When it is declared as public, the interface can be used by any other code. (When an interface is declared public, it must be in a file of the same name.) name is the name of the interface and can be any valid identifier.

Methods are declared using only their return type and signature. They are, essentially, abstract methods. As explained, in an interface, no method can have an implementation.
Thus, each class that includes an interface must implement all of the methods. In an interface, methods are implicitly public.

Variables declared in an interface are not instance variables. Instead, they are implicitly public, final, and static and must be initialized. Thus, they are essentially constants.

Here is an example of an interface definition. It specifies the interface to a class that generates a series of numbers.

```java
public interface Series {
    int getNext(); // return next number in series
    void reset(); // restart
    void setStart(int x); // set starting value
}
```

This interface is declared public so that it can be implemented by code in any package.

### Critical Skill 8.7 Implementing Interfaces

Once an interface has been defined, one or more classes can implement that interface. To implement an interface, include the implements clause in a class definition and then create the methods defined by the interface. The general form of a class that includes the implements clause looks like this:

```java
access class classname extends superclass implements interface {
    // class-body
}
```

Here, access is either public or not used. The extends clause is, of course, optional. To implement more than one interface, the interfaces are separated with a comma.

The methods that implement an interface must be declared public. Also, the type signature of the implementing method must match exactly the type signature specified in the interface definition.

Here is an example that implements the Series interface shown earlier. It creates a class called ByTwos, which generates a series of numbers, each two greater than the previous one.

```java
// Implement Series.
class ByTwos implements Series {
    int start;
    int val;

    ByTwos() {
        start = 0;
    }
}
```
val = 0;
}

public int getNext() {
    val += 2;
    return val;
}

public void reset() {
    start = 0;
    val = 0;
}

public void setStart(int x) {
    start = x;
    val = x;
}
}

Notice that the methods getNext(), reset(), and setStart() are declared using the public access specifier. This is necessary. Whenever you implement a method defined by an interface, it must be implemented as public because all members of an interface are implicitly public.

Here is a class that demonstrates ByTwos.

class SeriesDemo {
    public static void main(String args[]) {
        ByTwos ob = new ByTwos();

        for(int i=0; i < 5; i++)
            System.out.println("Next value is " + ob.getNext());

        System.out.println("\nResetting");
        ob.reset();
        for(int i=0; i < 5; i++)
            System.out.println("Next value is " + ob.getNext());

        System.out.println("\nStarting at 100");
        ob.setStart(100);
        for(int i=0; i < 5; i++)
            System.out.println("Next value is " + ob.getNext());
    }
}
The output from this program is shown here.

Next value is 2
Next value is 4
Next value is 6
Next value is 8
Next value is 10

Resetting
Next value is 2
Next value is 4
Next value is 6
Next value is 8
Next value is 10

Starting at 100
Next value is 102
Next value is 104
Next value is 106
Next value is 108
Next value is 110

It is both permissible and common for classes that implement interfaces to define additional members of their own. For example, the following version of ByTwos adds the method getPrevious(), which returns the previous value.

// Implement Series and add getPrevious().
class ByTwos implements Series {
    int start;
    int val;
    int prev;

    ByTwos() {
        start = 0;
        val = 0;
        prev = -2;
    }

    public int getNext() {
        prev = val;
        val += 2;
        return val;
    }

    public void reset() {
        start = 0;
    }
val = 0;
prev = -2;
}

public void setStart(int x) {
    start = x;
    val = x;
    prev = x - 2;
}

int getPrevious() {
    return prev;
}
}

Notice that the addition of `getPrevious()` required a change to the implementations of the methods defined by `Series`. However, since the interface to those methods stays the same, the change is seamless and does not break preexisting code. This is one of the advantages of interfaces.

As explained, any number of classes can implement an `interface`. For example, here is a class called `ByThrees` that generates a series that consists of multiples of three.

```java
// Implement Series.
class ByThrees implements Series {  // Implement Series a different way.
    int start;
    int val;

    ByThrees() {
        start = 0;
        val = 0;
    }

    public int getNext() {
        val += 3;
        return val;
    }

    public void reset() {
        start = 0;
        val = 0;
    }

    public void setStart(int x) {
        start = x;
        val = x;
    }
}
```
One more point: If a class includes an interface but does not fully implement the methods defined by that interface, then that class must be declared as **abstract**. No objects of such a class can be created, but it can be used as an abstract superclass, allowing subclasses to provide the complete implementation.

**CRITICAL SKILL 8.8**

Using Interface References

You might be somewhat surprised to learn that you can declare a reference variable of an interface type. In other words, you can create an interface reference variable. Such a variable can refer to any object that implements its interface. When you call a method on an object through an interface reference, it is the version of the method implemented by the object that is executed. This process is similar to using a superclass reference to access a subclass object, as described in Module 7.

The following example illustrates this process. It uses the same interface reference variable to called methods on objects of both **ByTwos** and **ByThrees**.

```java
// Demonstrate interface references.

class ByTwos implements Series {
   int start;
   int val;

   ByTwos() {
      start = 0;
      val = 0;
   }

   public int getNext() {
      val += 2;
      return val;
   }

   public void reset() {
      start = 0;
      val = 0;
   }

   public void setStart(int x) {
      start = x;
      val = x;
   }
}
```
class ByThrees implements Series {
    int start;
    int val;

    ByThrees() {
        start = 0;
        val = 0;
    }

    public int getNext() {
        val += 3;
        return val;
    }

    public void reset() {
        start = 0;
        val = 0;
    }

    public void setStart(int x) {
        start = x;
        val = x;
    }
}

class SeriesDemo2 {
    public static void main(String args[]) {
        ByTwos twoOb = new ByTwos();
        ByThrees threeOb = new ByThrees();
        Series ob;

        for(int i=0; i < 5; i++) {
            ob = twoOb;
            System.out.println("Next ByTwos value is " +
                    ob.getNext());
            ob = threeOb;
            System.out.println("Next ByThrees value is " +
                    ob.getNext());
        }
    }
}

In main(), ob is declared to be a reference to a Series interface. This means that it can be used to store references to any object that implements Series. In this case, it is used to refer to twoOb and threeOb, which are objects of type ByTwos and ByThrees, respectively,
which both implement Series. An interface reference variable has knowledge only of the methods declared by its interface declaration. Thus, ob could not be used to access any other variables or methods that might be supported by the object.

Progress Check

1. What is an interface? What keyword is used to define one?

2. What is implements for?

3. Can an interface reference variable refer to an object that implements that interface?

Project 8-1 Creating a Queue Interface

To see the power of interfaces in action, we will look at a practical example. In earlier modules, you developed a class called Queue that implemented a simple fixed-size queue for characters. However, there are many ways to implement a queue. For example, the queue can be of a fixed size or it can be “growable.” The queue can be linear, in which case it can be used up, or it can be circular, in which case elements can be put in as long as elements are being taken off. The queue can also be held in an array, a linked list, a binary tree, and so on. No matter how the queue is implemented, the interface to the queue remains the same, and the methods put() and get() define the interface to the queue independently of the details of the implementation. Because the interface to a queue is separate from its implementation, it is easy to define a queue interface, leaving it to each implementation to define the specifics.

In this project, you will create an interface for a character queue and three implementations. All three implementations will use an array to store the characters. One queue will be the fixed-size, linear queue developed earlier. Another will be a circular queue. In a circular queue, when the end of the underlying array is encountered, the get and put indices automatically loop back to the start. Thus, any number of items can be stored in a circular queue as long as items are also being taken out. The final implementation creates a dynamic queue, which grows as necessary when its size is exceeded.

1. An interface defines the methods that a class must implement but defines no implementation of its own. It is defined by the keyword interface.
2. To implement an interface, include that interface in a class by using the implements keyword.
3. Yes.
Step by Step

1. Create a file called `ICharQ.java` and put into that file the following interface definition.

   ```java
   // A character queue interface.
   public interface ICharQ {
     // Put a character into the queue.
     void put(char ch);

     // Get a character from the queue.
     char get();
   }
   }
   ``

   As you can see, this interface is very simple, consisting of only two methods. Each class that implements `ICharQ` will need to implement these methods.

2. Create a file called `IQDemo.java`.

3. Begin creating `IQDemo.java` by adding the `FixedQueue` class shown here:

   ```java
   // A fixed-size queue class for characters.
   class FixedQueue implements ICharQ {
     private char q[]; // this array holds the queue
     private int putloc, getloc; // the put and get indices

     // Construct an empty queue given its size.
     public FixedQueue(int size) {
       q = new char[size+1]; // allocate memory for queue
       putloc = getloc = 0;
     }

     // Put a character into the queue.
     public void put(char ch) {
       if(putloc==q.length-1) {
         System.out.println( " -- Queue is full.");
         return;
       }

       putloc++;
       q[putloc] = ch;
     }

     // Get a character from the queue.
     public char get() {
       if(getloc == putloc) {
         System.out.println( " -- Queue is empty.");
         return (char) 0;
       }

       char ch = q[getloc++];
       return ch;
     }
   }
   ```

(continued)
This implementation of ICharQ is adapted from the Queue class shown in Module 5 and should already be familiar to you.

4. To IQDemo.java add the CircularQueue class shown here. It implements a circular queue for characters.

```java
// A circular queue.
class CircularQueue implements ICharQ {
    private char q[]; // this array holds the queue
    private int putloc, getloc; // the put and get indices

    // Construct an empty queue given its size.
    public CircularQueue(int size) {
        q = new char[size+1]; // allocate memory for queue
        putloc = getloc = 0;
    }

    // Put a character into the queue.
    public void put(char ch) {
        if(putloc+1==getloc |
            ((putloc==q.length-1) & (getloc==0))) {
            System.out.println(" -- Queue is full.");
            return;
        }
        putloc++;
        if(putloc==q.length) putloc = 0; // loop back
        q[putloc] = ch;
    }

    // Get a character from the queue.
    public char get() {
        if(getloc == putloc) {
            System.out.println(" -- Queue is empty.");
            return (char) 0;
        }
        getloc++;
        if(getloc==q.length) getloc = 0; // loop back
    }
```

The implementation of get() and put() methods in circular queue class is given here.
package queuelist;

import java.util.*;

// A circular queue.
class CircularQueue implements ICharQ {
    private char q[]; // this array holds the queue
    private int putloc, getloc; // the put and get indices

    // Construct an empty queue given its size.
    public CircularQueue(int size) {
        q = new char[size+1]; // allocate memory for queue
        putloc = getloc = 0;
    }

    // Put a character into the queue.
    public void put(char ch) {
        if(putloc==q.length-1) {
            // increase queue size
            char t[] = new char[q.length * 2];

            // copy elements into new queue
            for(int i=0; i < q.length; i++)
                t[i] = q[i];

            q = t;
        }
        putloc++;
        q[putloc] = ch;
    }

    // Get a character from the queue.
    public char get() {
        return q[getloc++];
    }
}

The circular queue works by reusing space in the array that is freed when elements are retrieved. Thus, it can store an unlimited number of elements as long as elements are also being removed. While conceptually simple—just reset the appropriate index to zero when the end of the array is reached—the boundary conditions are a bit confusing at first. In a circular queue, the queue is full not when the end of the underlying array is reached, but rather when storing an item would cause an unretrieved item to be overwritten. Thus, put() must check several conditions in order to determine if the queue is full. As the comments suggest, the queue is full when either putloc is one less than getloc, or if putloc is at the end of the array and getloc is at the beginning. As before, the queue is empty when getloc and putloc are equal.

5. Put into IQDemo.java the DynQueue class shown next. It implements a “growable” queue that expands its size when space is exhausted.

    // A dynamic queue.
    class DynQueue implements ICharQ {
        private char q[]; // this array holds the queue
        private int putloc, getloc; // the put and get indices

        // Construct an empty queue given its size.
        public DynQueue(int size) {
            q = new char[size+1]; // allocate memory for queue
            putloc = getloc = 0;
        }

        // Put a character into the queue.
        public void put(char ch) {
            if(putloc==q.length-1) {
                // increase queue size
                char t[] = new char[q.length * 2];

                // copy elements into new queue
                for(int i=0; i < q.length; i++)
                    t[i] = q[i];

                q = t;
            }
            putloc++;
            q[putloc] = ch;
        }

        // Get a character from the queue.
        (continued)
public char get() {
    if (getloc == putloc) {
        System.out.println(" -- Queue is empty.");
        return (char) 0;
    }
    getloc++;
    return q[getloc];
}

In this queue implementation, when the queue is full, an attempt to store another element
causes a new underlying array to be allocated that is twice as large as the original, the
current contents of the queue are copied into this array, and a reference to the new array
is stored in \( q \).

6. To demonstrate the three \textbf{ICharQ} implementations, enter the following class into
\texttt{IQDemo.java}. It uses an \textbf{ICharQ} reference to access all three queues.

```java
// Demonstrate the ICharQ interface.
class IQDemo {
    public static void main(String args[]) {
        FixedQueue q1 = new FixedQueue(10);
        DynQueue q2 = new DynQueue(5);
        CircularQueue q3 = new CircularQueue(10);

        ICharQ iQ;

        char ch;
        int i;

        iQ = q1;
        // Put some characters into fixed queue.
        for (i = 0; i < 10; i++)
            iQ.put((char) ('A' + i));

        // Show the queue.
        System.out.print("Contents of fixed queue: ");
        for (i = 0; i < 10; i++) {
            ch = iQ.get();
            System.out.print(ch);
        }
        System.out.println();

        iQ = q2;
        // Put some characters into dynamic queue.
        for (i = 0; i < 10; i++)
```
iQ.put((char) ('Z' - i));

// Show the queue.
System.out.print("Contents of dynamic queue: ");
for(i=0; i < 10; i++) {
    ch = iQ.get();
    System.out.print(ch);
}

System.out.println();

iQ = q3;
// Put some characters into circular queue.
for(i=0; i < 10; i++)
    iQ.put((char) ('A' + i));

// Show the queue.
System.out.print("Contents of circular queue: ");
for(i=0; i < 10; i++) {
    ch = iQ.get();
    System.out.print(ch);
}

System.out.println();

// Put more characters into circular queue.
for(i=10; i < 20; i++)
    iQ.put((char) ('A' + i));

// Show the queue.
System.out.print("Contents of circular queue: ");
for(i=0; i < 10; i++) {
    ch = iQ.get();
    System.out.print(ch);
}

System.out.println();

System.out.println("\nStore and consume from circle queue.");

// Use and consume from circular queue.
for(i=0; i < 20; i++) {
    iQ.put((char) ('A' + i));
    ch = iQ.get();
    System.out.print(ch);
}
}
7. The output from this program is shown here.

Contents of fixed queue: ABCDEFGHIJ
Contents of dynamic queue: ZYXWVUTSRQ
Contents of circular queue: ABCDEFGHIJ
Contents of circular queue: KLMNOPQRST
Store and consume from circular queue.
ABCDEFGHIJKLMNOPQRST

8. Here are some things to try on your own. Create a circular version of \texttt{DynQueue}. Add a \texttt{reset()} method to \texttt{ICharQ} which resets the queue. Create a \texttt{static} method that copies the contents of one type of queue into another.

\textbf{CRITICAL SKILL 8.9 Variables in Interfaces}

As mentioned, variables can be declared in an interface, but they are implicitly \texttt{public}, \texttt{static}, and \texttt{final}. At first glance, you might think that there would be very limited use for such variables, but the opposite is true. Large programs typically make use of several constant values that describe such things as array size, various limits, special values, and the like. Since a large program is typically held in a number of separate source files, there needs to be a convenient way to make these constants available to each file. In Java, interface variables offer a solution.

To define a set of shared constants, simply create an \texttt{interface} that contains only these constants, without any methods. Each file that needs access to the constants simply “implements” the interface. This brings the constants into view. Here is a simple example.

```java
// An interface that contains constants.
interface IConst {
    int MIN = 0;
    int MAX = 10;
    String ERRORMSG = "Boundary Error";
}

class IConstD implements IConst {
    public static void main(String args[]) {
        int nums[] = new int[MAX];

        for(int i=MIN; i < 11; i++) {
            if(i >= MAX) System.out.println(ERRORMSG);
            else {
                nums[i] = i;
                System.out.print(nums[i] + " ");
            }
        }
    }
}
```

These are constants.
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 defined within 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();
}

// This class must implement all of A and B
class MyClass implements B {
    public void meth1() {
        System.out.println("Implement meth1().");
    }

    public void meth2() {
        System.out.println("Implement meth2().");
    }

    public void meth3() {
        System.out.println("Implement meth3().");
    }
}
```

**Ask the Expert**

**Q:** When I convert a C++ program to Java, how do I handle `#define` statements in a C++-style header file?

**A:** Java’s answer to the header files and `#defines` found in C++ is the interface and interface variables. To port a header file, simply perform a one-to-one translation.
class IFExtend {
    public static void main(String arg[]) {
        MyClass ob = new MyClass();
        ob.meth1();
        ob.meth2();
        ob.meth3();
    }
}

As an experiment, you might try removing the implementation for method1() in MyClass. This will cause a compile-time error. As stated earlier, any class that implements an interface must implement all methods defined by that interface, including any that are inherited from other 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 and applets 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.

Module 8 Mastery Check

1. Using the code from Project 8-1, put the ICharQ interface and its three implementations into a package called QPack. Keeping the queue demonstration class IQDemo in the default package, show how to import and use the classes in QPack.

2. What is a namespace? Why is it important that Java allows you to partition the namespace?

3. Packages are stored in ______________.

4. Explain the difference between protected and default access.

5. Explain the two ways that the members of a package can be used by other packages.

6. “One interface, multiple methods” is a key tenet of Java. What feature best exemplifies it?

7. How many classes can implement an interface? How many interfaces can a class implement?

8. Can interfaces be extended?
9. Create an interface for the **Vehicle** class from Module 7. Call the interface **IVehicle**.

10. Variables declared in an interface are implicitly **static** and **final**. What good are they?

11. A package is, in essence, a container for classes. True or False?

12. What standard Java package is automatically imported into a program?
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## Module 9

### Exception Handling

### CRITICAL SKILLS

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This module discusses exception handling. An exception is an error that occurs at run time. Using Java’s exception handling subsystem you can, in a structured and controlled manner, handle run-time errors. Although most modern programming languages offer some form of exception handling, Java’s support for it is cleaner and more flexible than most others.

A principal advantage of exception handling is that it automates much of the error handling code that previously had to be entered “by hand” into any large program. For example, in some computer languages, error codes are returned when a method fails, and these values must be checked manually, each time the method is called. This approach is both tedious and error-prone. Exception handling streamlines error handling by allowing your program to define a block of code, called an exception handler, that is executed automatically when an error occurs. It is not necessary to manually check the success or failure of each specific operation or method call. If an error occurs, it will be processed by the exception handler.

Another reason that exception handling is important is that Java defines standard exceptions for common program errors, such as divide-by-zero or file-not-found. To respond to these errors, your program must watch for and handle these exceptions. Also, Java’s API library makes extensive use of exceptions.

In the final analysis, to be a successful Java programmer means that you are fully capable of navigating Java’s exception handling subsystem.

### CRITICAL SKILL

#### 9.1 The Exception Hierarchy

In Java, all exceptions are represented by classes. All exception classes are derived from a class called **Throwable**. Thus, when an exception occurs in a program, an object of some type of exception class is generated. There are two direct subclasses of **Throwable**: **Exception** and **Error**. Exceptions of type **Error** are related to errors that occur in the Java virtual machine itself, and not in your program. These types of exceptions are beyond your control, and your program will not usually deal with them. Thus, these types of exceptions are not described here.

Errors that result from program activity are represented by subclasses of **Exception**. For example, divide-by-zero, array boundary, and file errors fall into this category. In general, your program should handle exceptions of these types. An important subclass of **Exception** is **RuntimeException**, which is used to represent various common types of run-time errors.

### CRITICAL SKILL

#### 9.2 Exception Handling Fundamentals

Java exception handling is managed via five keywords: **try**, **catch**, **throw**, **throws**, and **finally**. They form an interrelated subsystem in which the use of one implies the use of another.
Throughout the course of this module, each keyword is examined in detail. However, it is useful at the outset to have a general understanding of the role each plays in exception handling. 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`. In some cases, an exception that is thrown out of a method must be specified as such by a `throws` clause. Any code that absolutely must be executed upon exiting from a `try` block is put in a `finally` block.

**Ask the Expert**

**Q:** Just to be sure, could you review the conditions that cause an exception to be generated?

**A:** Exceptions are generated in three different ways. First, the Java virtual machine can generate an exception in response to some internal error which is beyond your control. Normally, your program won’t handle these types of exceptions. Second, standard exceptions, such as those corresponding to divide-by-zero or array index out-of-bounds, are generated by errors in program code. You need to handle these exceptions. Third, you can manually generate an exception by using the `throw` statement. No matter how an exception is generated, it is handled in the same way.

**Using try and catch**

At the core of exception handling are `try` and `catch`. These keywords work together; you can’t have a `try` without a `catch`, or a `catch` without a `try`. Here is the general form of the `try/catch` exception handling blocks:

```java
try {
    // block of code to monitor for errors
}
```

```java
catch (ExcepType1 exOb) {
    // handler for ExcepType1
}
```
catch (ExcepType2 exOb) {
    // handler for ExcepType2
}

Here, ExcepType is the type of exception that has occurred. When an exception is thrown, it is caught by its corresponding catch statement, which then processes the exception. As the general form shows, there can be more than one catch statement associated with a try. The type of the exception determines which catch statement is executed. That is, if the exception type specified by a catch statement matches that of the exception, then that catch statement is executed (and all others are bypassed). When an exception is caught, exOb will receive its value.

Here is an important point: If no exception is thrown, then a try block ends normally, and all of its catch statements are bypassed. Execution resumes with the first statement following the last catch. Thus, catch statements are executed only if an exception is thrown.

A Simple Exception Example

Here is a simple example that illustrates how to watch for and catch an exception. As you know, it is an error to attempt to index an array beyond its boundaries. When this occurs, the JVM throws an ArrayIndexOutOfBoundsException. The following program purposely generates such an exception and then catches it.

```java
// Demonstrate exception handling.
class ExcDemo1 {
    public static void main(String args[]) {
        int nums[] = new int[4];

        try {
            System.out.println("Before exception is generated.");
            // Generate an index out-of-bounds exception.
            nums[7] = 10;  // Attempt to index past nums boundary.
            System.out.println("this won't be displayed");
        }
        catch (ArrayIndexOutOfBoundsException exc) {
            // catch the exception
            System.out.println("Index out-of-bounds!");
        }
        System.out.println("After catch statement.");
    }
}
```
This program displays the following output:

Before exception is generated.
Index out-of-bounds!
After catch statement.

Although quite short, the preceding program illustrates several key points about exception handling. First, the code that you want to monitor for errors is contained within a `try` block. Second, when an exception occurs (in this case, because of the attempt to index `nums` beyond its bounds), the exception is thrown out of the `try` block and caught by the `catch` statement. At this point, control passes to the `catch`, and the `try` block is terminated. That is, `catch` is not called. Rather, program execution is transferred to it. Thus, the `println()` statement following the out-of-bounds index will never execute. After the `catch` statement executes, program control continues with the statements following the `catch`. Thus, it is the job of your exception handler to remedy the problem that caused the exception so that program execution can continue normally.

Remember, if no exception is thrown by a `try` block, no `catch` statements will be executed and program control resumes after the `catch` statement. To confirm this, in the preceding program, change the line

```java
nums[7] = 10;
```

to

```java
nums[0] = 10;
```

Now, no exception is generated, and the `catch` block is not executed.

It is important to understand that all code within a `try` block is monitored for exceptions. This includes exceptions that might be generated by a method called from within the `try` block. An exception thrown by a method called from within a `try` block can be caught by that `try` block—assuming, of course, that the method did not catch the exception itself. For example, this is a valid program:

```java
/* An exception can be generated by one
method and caught by another. */

class ExcTest {
    // Generate an exception.
    static void genException() {
        int nums[] = new int[4];

        System.out.println("Before exception is generated.");

        // generate an index out-of-bounds exception
```
nums[7] = 10; Exception generated here.
System.out.println("this won't be displayed");
}
}

class ExcDemo2 {
    public static void main(String args[]) {
        try {
            ExcTest.genException();
        }
        catch (ArrayIndexOutOfBoundsException exc) {
            // catch the exception
            System.out.println("Index out-of-bounds!");
        }
        System.out.println("After catch statement.");
    }
}

This program produces the following output, which is the same as that produced by the first version of the program shown earlier.

Before exception is generated.
Index out-of-bounds!
After catch statement.

Since genException() is called from within a try block, the exception that it generates (and does not catch) is caught by the catch in main(). Understand, however, that if genException() had caught the exception itself, it never would have been passed back to main().

Progress Check

1. What is an exception?
2. Code monitored for exceptions must be part of what statement?
3. What does catch do? After a catch executes, what happens to the flow of execution?

1. An exception is a run-time error.
2. To monitor code for exceptions, it must be part of a try block.
3. The catch statement receives exceptions. A catch statement is not called; thus execution does not return to the point at which the exception was generated. Rather, execution continues on after the catch block.
The Consequences of an Uncaught Exception

Catching one of Java’s standard exceptions, as the preceding program does, has a side benefit: It prevents abnormal program termination. When an exception is thrown, it must be caught by some piece of code, somewhere. In general, if your program does not catch an exception, then it will be caught by the JVM. The trouble is that the JVM’s default exception handler terminates execution and displays a stack trace and error message. For example, in this version of the preceding example, the index out-of-bounds exception is not caught by the program.

```java
// Let JVM handle the error.
class NotHandled {
    public static void main(String args[]) {
        int nums[] = new int[4];

        System.out.println("Before exception is generated.");

        // generate an index out-of-bounds exception
        nums[7] = 10;
    }
}
```

When the array index error occurs, execution is halted, and the following error message is displayed.

```
Exception in thread "main" java.lang.ArrayIndexOutOfBoundsException
    at NotHandled.main(NotHandled.java:9)
```

While such a message is useful for you while debugging, it would not be something that you would want others to see, to say the least! This is why it is important for your program to handle exceptions itself, rather than rely upon the JVM.

As mentioned earlier, the type of the exception must match the type specified in a `catch` statement. If it doesn’t, the exception won’t be caught. For example, the following program tries to catch an array boundary error with a `catch` statement for an ArithmeticException (another of Java’s built-in exceptions). When the array boundary is overrun, an ArrayIndexOutOfBoundsException is generated, but it won’t be caught by the `catch` statement. This results in abnormal program termination.

```java
// This won't work!
class ExcTypeMismatch {
    public static void main(String args[]) {
```
int nums[] = new int[4];

try {
    System.out.println("Before exception is generated.");

    // generate an index out-of-bounds exception
    nums[7] = 10;
    System.out.println("this won't be displayed");
}

/* Can't catch an array boundary error with an
   ArithmeticException. */
catch (ArithmeticException exc) {
    // catch the exception
    System.out.println("Index out-of-bounds!");
}
System.out.println("After catch statement.");
}
}

The output is shown here.

Before exception is generated.
Exception in thread "main" java.lang.ArrayIndexOutOfBoundsException
    at ExcTypeMismatch.main(ExcTypeMismatch.java:10)

As the output demonstrates, a catch for ArithmeticException won't catch an
ArrayIndexOutOfBoundsException.

Exceptions Enable You to Handle Errors Gracefully

One of the key benefits of exception handling is that it enables your program to respond to an error
and then continue running. For example, consider the following example that divides the elements
of one array by the elements of another. If a division by zero occurs, an ArithmeticException is
generated. In the program, this exception is handled by reporting the error and then continuing with
execution. Thus, attempting to divide by zero does not cause an abrupt run-time error resulting in
the termination of the program. Instead, it is handled gracefully, allowing program execution to
continue.

// Handle error gracefully and continue.
class ExcDemo3 {
    public static void main(String args[]) {
        int numer[] = { 4, 8, 16, 32, 64, 128 };
        int denom[] = { 2, 0, 4, 4, 0, 8 };
    }
}
for(int i=0; i<numer.length; i++) {
    try {
        System.out.println(numer[i] + " / " +
            denom[i] + " is " +
            numer[i]/denom[i]);
    } catch (ArithmeticException exc) {
        // catch the exception
        System.out.println("Can't divide by Zero!");
    }
}

The output from the program is shown here.

4 / 2 is 2
Can't divide by Zero!
16 / 4 is 4
32 / 4 is 8
Can't divide by Zero!
128 / 8 is 16

This example makes another important point: Once an exception has been handled, it is removed from the system. Therefore, in the program, each pass through the loop enters the try block anew; any prior exceptions have been handled. This enables your program to handle repeated errors.

Progress Check

1. Does the exception type in a catch statement matter?
2. What happens if an exception is not caught?
3. When an exception occurs, what should your program do?

1. The type of exception in a catch must match the type of exception that you want to catch.
2. An uncaught exception ultimately leads to abnormal program termination.
3. A program should handle exceptions in a rational, graceful manner, eliminating the cause of the exception if possible and then continuing.
Using Multiple catch Statements

As stated earlier, you can associate more than one `catch` statement with a `try`. In fact, it is common to do so. However, each `catch` must catch a different type of exception. For example, the program shown here catches both array boundary and divide-by-zero errors.

```java
// Use multiple catch statements.
class ExcDemo4 {
    public static void main(String args[]) {
        // Here, numer is longer than denom.
        int numer[] = { 4, 8, 16, 32, 64, 128, 256, 512 };  
        int denom[] = { 2, 0, 4, 4, 0, 8 };  

        for(int i=0; i<numer.length; i++) {
            try {
                System.out.println(numer[i] + " / " + 
                denom[i] + " is " + 
                numer[i]/denom[i]);

            }catch (ArithmeticException exc) {
                // catch the exception
                System.out.println("Can't divide by Zero!");
            }
            catch (ArrayIndexOutOfBoundsException exc) {
                // catch the exception
                System.out.println("No matching element found.");
            }
        }
    }
}
```

This program produces the following output:

```
4 / 2 is 2
Can't divide by Zero!
16 / 4 is 4
32 / 4 is 8
Can't divide by Zero!
128 / 8 is 16
No matching element found.
No matching element found.
```

As the output confirms, each `catch` statement responds only to its own type of exception.

In general, `catch` expressions are checked in the order in which they occur in a program. Only a matching statement is executed. All other `catch` blocks are ignored.
Catching Subclass Exceptions

There is one important point about multiple catch statements that relates to subclasses. A catch clause for a superclass will also match any of its subclasses. For example, since the superclass of all exceptions is Throwable, to catch all possible exceptions, catch Throwable. If you want to catch exceptions of both a superclass type and a subclass type, put the subclass first in the catch sequence. If you don’t, then the superclass catch will also catch all derived classes. This rule is self-enforcing because putting the superclass first causes unreachable code to be created, since the subclass catch clause can never execute. In Java, unreachable code is an error.

For example, consider the following program.

```java
// Subclasses must precede superclasses in catch statements.
class ExcDemo5 {
    public static void main(String args[]) {
        // Here, numer is longer than denom.
        int numer[] = { 4, 8, 16, 32, 64, 128, 256, 512 };
        int denom[] = { 2, 0, 4, 4, 0, 8 };
        for(int i=0; i<numer.length; i++) {
            try {
                System.out.println(numer[i] + " / " +
                denom[i] + " is " +
                numer[i]/denom[i]);
            } catch (ArrayIndexOutOfBoundsException exc) {
                // catch the exception
                System.out.println("No matching element found.");
            } catch (Throwable exc) {
                System.out.println("Some exception occurred.");
            }
        }
    }
}
```

The output from the program is shown here.

```
4 / 2 is 2
Some exception occurred.
16 / 4 is 4
32 / 4 is 8
Some exception occurred.
128 / 8 is 16
No matching element found.
No matching element found.
```
In this case, `catch(Throwables)` catches all exceptions except for `ArrayIndexOutOfBoundsException`.

The issue of catching subclass exceptions becomes more important when you create exceptions of your own.

**Ask the Expert**

**Q:** Why would I want to catch superclass exceptions?

**A:** There are, of course, a variety of reasons. Here are a couple. First, if you add a `catch` clause that catches exceptions of type `Exception`, then you have effectively added a “catch all” clause to your exception handler that deals with all program-related exceptions. Such a “catch all” clause might be useful in a situation in which abnormal program termination must be avoided no matter what occurs. Second, in some situations, an entire category of exceptions can be handled by the same clause. Catching the superclass of these exceptions allows you to handle all without duplicated code.

**Critical Skill 9.6 Try Blocks Can Be Nested**

One `try` block can be nested within another. An exception generated within the inner `try` block that is not caught by a `catch` associated with that `try` is propagated to the outer `try` block. For example, here the `ArrayIndexOutOfBoundsException` is not caught by the inner `try` block, but by the outer `try`.

```java
// Use a nested try block.
class NestTrys {
    public static void main(String args[]) {
        // Here, numer is longer than denom.
        int numer[] = { 4, 8, 16, 32, 64, 128, 256, 512 };  
        int denom[] = { 2, 0, 4, 4, 0, 8 };  

        try { // outer try
            for(int i=0; i<numer.length; i++) {
                try { // nested try
                    System.out.println(numer[i] + " / " +
                                      denom[i] + " is " +
                                      numer[i]/denom[i]);
                } catch (ArithmeticException exc) {
                    // catch the exception
                }
            }
        }
    }
}
```
The output from the program is shown here.

4 / 2 is 2
Can't divide by Zero!
16 / 4 is 4
32 / 4 is 8
Can't divide by Zero!
128 / 8 is 16
No matching element found.
Fatal error -- program terminated.

In this example, an exception that can be handled by the inner try—in this case, a divide-by-zero error—allows the program to continue. However, an array boundary error is caught by the outer try, which causes the program to terminate.

Although certainly not the only reason for nested try statements, the preceding program makes an important point that can be generalized. Often nested try blocks are used to allow different categories of errors to be handled in different ways. Some types of errors are catastrophic and cannot be fixed. Some are minor and can be handled immediately. Many programmers use an outer try block to catch the most severe errors, allowing inner try blocks to handle less serious ones.

**Progress Check**

1. Can one try block be used to catch two or more different types of exceptions?
2. Can a catch statement for a superclass exception also catch subclasses of that superclass?
3. In nested try blocks, what happens to an exception that is not caught by the inner block?

1. Yes.
2. Yes.
3. An exception not caught by an inner try/catch block moves outward to the enclosing try block.
Throwing an Exception

The preceding examples have been catching exceptions generated automatically by the JVM. However, it is possible to manually throw an exception by using the `throw` statement. Its general form is shown here.

```
throw exceptOb;
```

Here, `exceptOb` must be an object of an exception class derived from `Throwable`.

Here is an example that illustrates the `throw` statement by manually throwing an `ArithmeticException`.

```
// Manually throw an exception.
class ThrowDemo {
    public static void main(String args[]) {
        try {
            System.out.println("Before throw.");
            throw new ArithmeticException(); // Throw an exception.
        }
        catch (ArithmeticException exc) {
            // catch the exception
            System.out.println("Exception caught.");
        }
        System.out.println("After try/catch block.");
    }
}
```

The output from the program is shown here.

Before throw.
Exception caught.
After try/catch block.

Notice how the `ArithmeticException` was created using `new` in the `throw` statement. Remember, `throw` throws an object. Thus, you must create an object for it to throw. That is, you can’t just throw a type.

Rethrowing an Exception

An exception caught by one `catch` statement can be rethrown so that it can be caught by an outer `catch`. The most likely reason for rethrowing this way is to allow multiple handlers access to the exception. For example, perhaps one exception handler manages one aspect of an exception, and a second handler copes with another aspect. Remember, when you rethrow an
exception, it will not be recaught by the same catch statement. It will propagate to the next catch statement.

The following program illustrates rethrowing an exception.

```java
// Rethrow an exception.
class Rethrow {
    public static void genException() {
        // here, numer is longer than denom
        int numer[] = { 4, 8, 16, 32, 64, 128, 256, 512 };  
        int denom[] = { 2, 0, 4, 4, 0, 8 };  

        for(int i=0; i<numer.length; i++) {
            try {
                System.out.println(numer[i] + " / " + 
                                  denom[i] + " is " + 
                                  numer[i]/denom[i]);
            }
            catch (ArithmeticException exc) {
                // catch the exception
                System.out.println("Can't divide by Zero!");
            }
            catch (ArrayIndexOutOfBoundsException exc) {
                // catch the exception
                System.out.println("No matching element found.");
                throw exc;  // rethrow the exception
            }
        }
    }
}

class RethrowDemo {
    public static void main(String args[]) {
        try {
            Rethrow.genException();
        }
    }
}
```

**Q:** Why would I want to manually throw an exception?

**A:** Most often, the exceptions that you will throw will be instances of exception classes that you created. As you will see later in this module, creating your own exception classes allows you to handle errors in your code as part of your program’s overall exception handling strategy.
In this program, divide-by-zero errors are handled locally, by `genException()`, but an array boundary error is rethrown. In this case, it is caught by `main()`.

**Progress Check**

1. What does `throw` do?
2. Does `throw` throw types or objects?
3. Can an exception be rethrown after it is caught?

### CRITICAL SKILL 9.8 A Closer Look at Throwable

Up to this point, we have been catching exceptions, but we haven’t been doing anything with the exception object itself. As the preceding examples all show, a `catch` clause specifies an exception type and a parameter. The parameter receives the exception object. Since all exceptions are subclasses of `Throwable`, all exceptions support the methods defined by `Throwable`. Several commonly used ones are shown in Table 9-1.

Of the methods defined by `Throwable`, the three of greatest interest are `printStackTrace()`, `getMessage()`, and `toString()`. You can display the standard error message plus a record of the method calls that lead up to the exception by calling `printStackTrace()`. To obtain Java’s standard error message for an exception, call `getMessage()`. Alternatively, you can use `toString()` to retrieve the standard message. The `toString()` method is also called when an exception is used as an argument to `println()`. The following program demonstrates these methods.

---

1. `throw` generates an exception.
2. `throw` throws objects. These objects must be instances of valid exception classes, of course.
3. Yes.
// Using the Throwable methods.

class ExcTest {
    static void genException() {
        int nums[] = new int[4];

        System.out.println("Before exception is generated.");

        // generate an index out-of-bounds exception
        nums[7] = 10;
        System.out.println("this won't be displayed");
    }
}

class UseThrowableMethods {
    public static void main(String args[]) {
        try {
            ExcTest.genException();
        }
        catch (ArrayIndexOutOfBoundsException exc) {
            // catch the exception
            System.out.println("Standard message is: ");
            System.out.println(exc);
            System.out.println("\nStack trace: ");
            exc.printStackTrace(); //"Index out-of-bounds!");
        }
    }
}

Table 9-1  Commonly Used Methods Defined by Throwable

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<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>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>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>String toString()</td>
<td>Returns a String object containing a description of the exception. This method is called by println() when outputting a Throwable object.</td>
</tr>
</tbody>
</table>

Method Description:
- Throwable.fillInStackTrace(): Returns a Throwable object that contains a completed stack trace. This object can be rethrown.
- String.getLocalizedMessage(): Returns a localized description of the exception.
- String.getMessage(): Returns a description of the exception.
- void.printStackTrace(): Displays the stack trace.
- void.printStackTrace(PrintStream stream): Sends the stack trace to the specified stream.
- void.printStackTrace(PrintWriter stream): Sends the stack trace to the specified stream.
- String.toString(): Returns a String object containing a description of the exception. This method is called by println() when outputting a Throwable object.
System.out.println("After catch statement.");
}
}

The output from this program is shown here.

Before exception is generated.
Standard message is:
java.lang.ArrayIndexOutOfBoundsException

Stack trace:
java.lang.ArrayIndexOutOfBoundsException
  at ExcTest.genException(UseThrowableMethods.java:10)
  at UseThrowableMethods.main(UseThrowableMethods.java:19)
After catch statement.

CRITICAL SKILL

Using finally

Sometimes you will want to define a block of code that will execute when a try/catch block is left. For example, an exception might cause an error that terminates the current method, causing its premature return. However, that method may have opened a file or a network connection that needs to be closed. Such types of circumstances are common in programming, and Java provides a convenient way to handle them: finally.

To specify a block of code to execute when a try/catch block is exited, include a finally block at the end of a try/catch sequence. The general form of a try/catch that includes finally is shown here.

try {
    // block of code to monitor for errors
}

catch (ExcepType1 exOb) {
    // handler for ExcepType1
}

catch (ExcepType2 exOb) {
    // handler for ExcepType2
}

//...
finally {
    // finally code
}
The **finally** block will be executed whenever execution leaves a **try/catch** block, no matter what conditions cause it. That is, whether the **try** block ends normally, or because of an exception, the last code executed is that defined by **finally**. The **finally** block is also executed if any code within the **try** block or any of its **catch** statements return from the method.

Here is an example of **finally**.

```java
// Use finally.
class UseFinally {
    public static void genException(int what) {
        int t;
        int nums[] = new int[2];

        System.out.println("Receiving " + what);
        try {
            switch(what) {
                case 0:
                    t = 10 / what; // generate div-by-zero error
                    break;
                case 1:
                    break;
                case 2:
                    return; // return from try block
            }
        }
        catch (ArithmeticException exc) {
            // catch the exception
            System.out.println("Can't divide by Zero!");
            return; // return from catch
        }
        catch (ArrayIndexOutOfBoundsException exc) {
            // catch the exception
            System.out.println("No matching element found.");
        }
        finally { // This is executed on way out of try/catch blocks.
            System.out.println("Leaving try.");
        }
    }
}

class FinallyDemo {
    public static void main(String args[]) {
        for(int i=0; i < 3; i++) {
            UseFinally.genException(i);
        }
    }
}
Here is the output produced by the program.

Receiving 0
Can't divide by Zero!
Leaving try.

Receiving 1
No matching element found.
Leaving try.

Receiving 2
Leaving try.

As the output shows, no matter how the try block is exited, the finally block executed.

Progress Check

1. Exception classes are subclasses of what class?
2. When is the code within a finally block executed?
3. How can you display a stack trace of the events leading up to an exception?

Using throws

In some cases, if a method generates an exception that it does not handle, it must declare that exception in a throws clause. Here is the general form of a method that includes a throws clause.

```
ret-type methName(param-list) throws except-list {
    // body
}
```

Here, except-list is a comma-separated list of exceptions that the method might throw outside of itself.

1. Throwable.
2. A finally block is the last thing executed when a try block is exited.
3. To print a stack trace, call printStackTrace(), which is defined by Throwable.
You might be wondering why you did not need to specify a `throws` clause for some of the preceding examples, which threw exceptions outside of methods. The answer is that exceptions that are subclasses of `Error` or `RuntimeException` don’t need to be specified in a `throws` list. Java simply assumes that a method may throw one. All other types of exceptions do need to be declared. Failure to do so causes a compile-time error.

Actually, you saw an example of a `throws` clause earlier in this book. As you will recall, when performing keyboard input, you needed to add the clause

```java
throws java.io.IOException
```
to `main()`. Now you can understand why. An input statement might generate an `IOException`, and at that time, we weren’t able to handle that exception. Thus, such an exception would be thrown out of `main()` and needed to be specified as such. Now that you know about exceptions, you can easily handle `IOException`.

Let’s look at an example that handles `IOException`. It creates a method called `prompt()`, which displays a prompting message and then reads a character from the keyboard. Since input is being performed, an `IOException` might occur. However, the `prompt()` method does not handle `IOException` itself. Instead, it uses a `throws` clause, which means that the calling method must handle it. In this example, the calling method is `main()`, and it deals with the error.

```java
// Use throws.
class ThrowsDemo {
    public static char prompt(String str) throws java.io.IOException {
        System.out.print(str + ": ");
        return (char) System.in.read();
    }

    public static void main(String args[]) {
        char ch;
        try {
            ch = prompt("Enter a letter");
        } catch(java.io.IOException exc) {
            System.out.println("I/O exception occurred.");
            ch = 'X';
        }

        System.out.println("You pressed " + ch);
    }
}
```

On a related point, notice that `IOException` is fully qualified by its package name `java.io`. As you will learn in Module 10, Java’s I/O system is contained in the `java.io` package. Thus,
the IOException is also contained there. It would also have been possible to import java.io and then refer to IOException directly.

**CRITICAL SKILL**

**9.11 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. Since java.lang is implicitly imported into all Java programs, most exceptions derived from RuntimeException are automatically available. Furthermore, they 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 9-2. Table 9-3 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*. Java defines several other types of exceptions that relate to its various class libraries, such as IOException mentioned earlier.

<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>IllegalArgumentException</td>
<td>Illegal argument used to invoke a method.</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>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>UnsupportedOperationException</td>
<td>An unsupported operation was encountered.</td>
</tr>
</tbody>
</table>

**Table 9-2** The Unchecked Exceptions Defined in java.lang
### Exception Handling

<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 Cloneable 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>
</tbody>
</table>

**Table 9-3** The Checked Exceptions Defined in java.lang

---

## Ask the Expert

**Q:** I have heard that Java supports something called *chained exceptions*. What are they?

**A:** Chained exceptions are a very recent addition to Java, having been added in 2002 by Java 2, version 1.4. The chained exception feature allows you to specify one exception as the underlying cause of another. 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, Java 2, version 1.4 added two constructors and two methods to `Throwable`. The constructors are shown here:

```java
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

(continued)
two constructors have also been added to the Error, Exception, and RuntimeException classes.

The chained exception methods added to Throwable are getCause() and initCause().

These methods are shown here:

Runnable getCause( )

Runnable 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. In general, initCause() is used to set a cause for legacy exception classes that don’t support the two additional constructors described earlier. At the time of this writing, most of Java’s built-in exceptions, such as ArithmeticException, do not define additional cause-related constructors. Thus, you will use initCause() if you need to add an exception chain to these exceptions.

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.

Progress Check

1. What is throws used for?

2. What is the difference between checked and unchecked exceptions?

3. If a method generates an exception that it handles, must it include a throws clause for the exception?

Creating Exception Subclasses

Although Java’s built-in exceptions handle most common errors, Java’s exception handling mechanism is not limited to these errors. In fact, part of the power of Java’s approach to exceptions is its ability to handle exceptions that you create which correspond to errors in your own code. Creating an exception is easy. Just define a subclass of Exception (which is, of

1. When a method generates an exception that it does not handle, it must state this fact using a throws clause.

2. No throws clause is needed for unchecked exceptions.

3. No. A throws clause is needed only when the method does not handle the exception.
course, a subclass of \texttt{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 \texttt{Exception} class does not define any methods of its own. It does, of course, inherit those methods provided by \texttt{Throwable}. Thus, all exceptions, including those that you create, have the methods defined by \texttt{Throwable} available to them. Of course, you can override one or more of these methods in exception subclasses that you create.

Here is an example that creates an exception called \texttt{NonIntResultException}, which is generated when the result of dividing two integer values produces a result with a fractional component. \texttt{NonIntResultException} has two fields which hold the integer values, a constructor and an override of the \texttt{toString()} method, allowing the description of the exception to be displayed using \texttt{println( )}.

\begin{verbatim}
// Use a custom exception.

// Create an exception.
class NonIntResultException extends Exception {
    int n;
    int d;

    NonIntResultException(int i, int j) {
        n = i;
        d = j;
    }

    public String toString() {
        return "Result of " + n + " / " + d +
            " is non-integer."
    }
}

class CustomExceptDemo {
    public static void main(String args[]) {

        // Here, numer contains some odd values.
        int numer[] = { 4, 8, 15, 32, 64, 127, 256, 512 };
        int denom[] = { 2, 0, 4, 4, 0, 8 };
        for(int i=0; i<numer.length; i++) {
            try {
                if((numer[i]%2) != 0)
                    throw new
                        NonIntResultException(numer[i], denom[i]);

                System.out.println(numer[i] + " / " +
                    denom[i] + " is " +
                    numer[i]/denom[i]);
            }
        }
    }
}
\end{verbatim}
```java
} catch (ArithmeticException exc) {
    // catch the exception
    System.out.println("Can't divide by Zero!");
} catch (ArrayIndexOutOfBoundsException exc) {
    // catch the exception
    System.out.println("No matching element found.");
} catch (NonIntResultException exc) {
    System.out.println(exc);
}
}
```

The output from the program is shown here.

```
4 / 2 is 2
Can't divide by Zero!
Result of 15 / 4 is non-integer.
32 / 4 is 8
Can't divide by Zero!
Result of 127 / 8 is non-integer.
No matching element found.
No matching element found.
```

---

**Ask the Expert**

**Q:** When should I use exception handling in a program? When should I create my own custom exception classes?

**A:** Since the Java API makes extensive use of exceptions to report errors, nearly all real-world programs will make use of exception handling. This is the part of exception handling that most new Java programmers find easy. It is harder to decide when and how to use your own custom-made exceptions. In general, errors can be reported in two ways: return values and exceptions. When is one approach better than the other? Simply put, in Java, exception handling should be the norm. Certainly returning an error code is a valid alternative in some cases, but exceptions provide a more powerful, structured way to handle errors. They are the way professional Java programmers handle errors in their code.
In this project, you will create two exception classes that can be used by the queue classes developed by Project 8-1. They will indicate the queue-full and queue-empty error conditions. These exceptions can be thrown by the put() and get() methods, respectively. For the sake of simplicity, this project will add these exceptions to the FixedQueue class, but you can easily incorporate them into the other queue classes from Project 8-1.

Step by Step

1. Create a file called QExcDemo.java.

2. Into QExcDemo.java, define the following exceptions.

```java
/*
   Project 9-1

   Add exception handling to the queue classes.
*/

// An exception for queue-full errors.
class QueueFullException extends Exception {
    int size;

    QueueFullException(int s) { size = s; }

    public String toString() {
        return "Queue is full. Maximum size is " +
                size;
    }
}

// An exception for queue-empty errors.
class QueueEmptyException extends Exception {

    public String toString() {
        return "Queue is empty.";
    }
}

A QueueFullException is generated when an attempt is made to store an item in an already full queue. A QueueEmptyException is generated when an attempt is made to remove an element from an empty queue.
3. Modify the `FixedQueue` class so that it throws exceptions when an error occurs, as shown here. Add it to `QExcDemo.java`.

```java
// A fixed-size queue class for characters that uses exceptions.
class FixedQueue implements ICharQ {
    private char q[]; // this array holds the queue
    private int putloc, getloc; // the put and get indices

    // Construct an empty queue given its size.
    public FixedQueue(int size) {
        q = new char[size+1]; // allocate memory for queue
        putloc = getloc = 0;
    }

    // Put a character into the queue.
    public void put(char ch) throws QueueFullException {
        if(putloc==q.length-1)
            throw new QueueFullException(q.length-1);
        putloc++;
        q[putloc] = ch;
    }

    // Get a character from the queue.
    public char get() throws QueueEmptyException {
        if(getloc == putloc)
            throw new QueueEmptyException();
        getloc++;
        return q[getloc];
    }
}
```

Notice that two steps are required to add exceptions to `FixedQueue`. First, `get()` and `put()` must have a `throws` clause added to their declarations. Second, when an error occurs, these methods throw an exception. Using exceptions allows the calling code to handle the error in a rational fashion. You might recall that the previous versions simply reported the error. Throwing an exception is a much better approach.

4. To try the updated `FixedQueue` class, add the `QExcDemo` class shown here to `QExcDemo.java`. 
// Demonstrate the queue exceptions.
class QExcDemo {
    public static void main(String args[]) {
        FixedQueue q = new FixedQueue(10);
        char ch;
        int i;

        try {
            // overrun the queue
            for(i=0; i < 11; i++) {
                System.out.print("Attempting to store: ");
                System.out.print((char) ('A' + i));
                q.put((char) ('A' + i));
                System.out.println(" -- OK");
            }
            System.out.println();
        }
        catch (QueueFullException exc) {
            System.out.println(exc);
        }
        System.out.println();

        try {
            // over-empty the queue
            for(i=0; i < 11; i++) {
                System.out.print("Getting next char:");
                ch = q.get();
                System.out.println(ch);
            }
        }
        catch (QueueEmptyException exc) {
            System.out.println(exc);
        }
    }
}

5. Since FixedQueue implements the ICharQ interface, which defines the two queue methods get() and put(), ICharQ will need to be changed to reflect the throws clause. Here is the updated ICharQ interface. Remember, this must be in a file by itself called ICharQ.java.

    // A character queue interface that throws exceptions.
    public interface ICharQ {
        // Put a character into the queue.
        void put(char ch) throws QueueFullException;
    }

    (continued)
6. Now, compile the updated IQChar.java file. Then, compile QExcDemo.java. Finally, run QExcDemo. You will see the following output.

```
Attempting to store : A -- OK
Attempting to store : B -- OK
Attempting to store : C -- OK
Attempting to store : D -- OK
Attempting to store : E -- OK
Attempting to store : F -- OK
Attempting to store : G -- OK
Attempting to store : H -- OK
Attempting to store : I -- OK
Attempting to store : J -- OK
Attempting to store : K
Queue is full. Maximum size is 10

Getting next char: A
Getting next char: B
Getting next char: C
Getting next char: D
Getting next char: E
Getting next char: F
Getting next char: G
Getting next char: H
Getting next char: I
Getting next char: J
Getting next char:
Queue is empty.
```

### Module 9 Mastery Check

1. What class is at the top of the exception hierarchy?
2. Briefly explain how to use try and catch.
3. What is wrong with this fragment?

```java
// ...
vals[18] = 10;
catch (ArrayIndexOutOfBoundsException exc) {
    // handle error
}
```
4. What happens if an exception is not caught?

5. What is wrong with this fragment?

```java
class A extends Exception {
    ...
}
class B extends A {
    ...
}
// ...
try {
    // ...
} 
catch (A exc) { ... }
catch (B exc) { ... }
```

6. Can an exception caught by an inner catch rethrow that exception to an outer catch?

7. The finally block is the last bit of code executed before your program ends. True or False? Explain your answer.

8. What type of exceptions must be explicitly declared in a throws clause of a method?

9. What is wrong with this fragment?

```java
class MyClass {
    // ...
} 
// ...
thrown new MyClass();
```

10. In Exercise 3 of the Mastery Check in Module 6, you created a Stack class. Add custom exceptions to your class that report stack full and stack empty conditions.

11. What are the three ways that an exception can be generated?

12. What are the two direct subclasses of Throwable?
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# Module 10

Using I/O

## CRITICAL SKILLS

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<th>10.1</th>
<th>Understand the stream</th>
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<td>10.2</td>
<td>Know the difference between byte and character streams</td>
</tr>
<tr>
<td>10.3</td>
<td>Know Java’s byte stream classes</td>
</tr>
<tr>
<td>10.4</td>
<td>Know Java’s character stream classes</td>
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<td>10.10</td>
<td>Use character streams</td>
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<tr>
<td>10.11</td>
<td>Use character streams for file I/O</td>
</tr>
<tr>
<td>10.12</td>
<td>Apply Java’s type wrappers to convert numeric strings</td>
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</table>
Since the beginning of this book, you have been using parts of the Java I/O system, such as `println()`. However, you have been doing so without much formal explanation. Because the Java I/O system is based upon a hierarchy of classes, it was not possible to present its theory and details without first discussing classes, inheritance, and exceptions. Now it is time to examine Java’s approach to I/O in detail.

Be forewarned, Java’s I/O system is quite large, containing many classes, interfaces, and methods. Part of the reason for its size is that Java defines two complete I/O systems: one for byte I/O and the other for character I/O. It won’t be possible to discuss every aspect of Java’s I/O here. (An entire book could easily be dedicated to Java’s I/O system!) This module will, however, introduce you to the most important and commonly used features. Fortunately, Java’s I/O system is cohesive and consistent; once you understand its fundamentals, the rest of the I/O system is easy to master.

This module examines Java’s approach to both console I/O and file I/O. Before we begin, however, it is important to emphasize a point made earlier in this book: most real applications of Java will not be text-based, console programs. Rather, they will be graphically oriented applets that rely upon a windowed interface for interaction with the user. Thus, the portion of Java’s I/O system that relates to console input and output is not widely used in commercial code. Although text-based programs are excellent as teaching examples, they do not constitute an important use for Java in the real world. In Module 12 you will see how applets are created and learn the basics of Java’s support of a graphical user interface.

**Critical Skill 10.1: Java’s I/O Is Built upon 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 they are linked to differ. Thus, the same I/O classes and methods can be applied to any type of device. For example, the same methods that you use to write to the console can also be used to write to a disk file. Java implements streams within class hierarchies defined in the `java.io` package.

**Critical Skill 10.2: Byte Streams and Character Streams**

Modern versions of Java define two types of streams: byte and character. (The original version of Java defined only the byte stream, but character streams were quickly added.) Byte streams provide a convenient means for handling input and output of bytes. They are used, for example, when reading or writing binary data. They are especially helpful when working with files. Character streams are designed for handling the 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 fact that Java defines two different types of streams makes the I/O system quite large because two separate sets of class hierarchies (one for bytes, one for characters) is needed. The sheer number of I/O classes can make the I/O system appear more intimidating than it actually is. Just remember, for the most part, the functionality of byte streams is paralleled by that of the character streams.

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.

### The Byte Stream Classes

Byte streams are defined by using two class hierarchies. At the top of these are two abstract classes: `InputStream` and `OutputStream`. `InputStream` defines the characteristics common to byte input streams and `OutputStream` describes the behavior of byte output streams.

From `InputStream` and `OutputStream` are created several concrete subclasses that offer varying functionality and handle the details of reading and writing to various devices, such as disk files. The byte stream classes are shown in Table 10-1. Don’t be overwhelmed by the number of different classes. Once you can use one byte stream, the others are easy to master.

### The Character Stream Classes

Character streams are defined by using two class hierarchies topped by these two abstract classes: `Reader` and `Writer`. `Reader` is used for input, and `Writer` is used for output. Concrete classes derived from `Reader` and `Writer` operate on Unicode character streams.

From `Reader` and `Writer` are derived several concrete subclasses that handle various I/O situations. In general, the character-based classes parallel the byte-based classes. The character stream classes are shown in Table 10-2.

### 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. Among other things, it contains three predefined stream variables, called `in`, `out`, and `err`. These fields are declared as `public` and `static` 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 by default the keyboard. System.err refers to the standard error stream, which is also the console by default. However, these streams can 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. The reason they are byte and not character streams is that the predefined streams were part of the original specification for Java, which did not include the character streams. As you will see, it is possible to wrap these within character-based streams if desired.

### Table 10-1 The Byte Stream Classes

<table>
<thead>
<tr>
<th>Byte 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>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 <code>print()</code> and <code>println()</code></td>
</tr>
<tr>
<td>PushbackInputStream</td>
<td>Input stream that allows bytes to be returned to the stream</td>
</tr>
<tr>
<td>RandomAccessFile</td>
<td>Supports random access file I/O</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>
Progress Check

1. What is a stream?

2. What types of streams does Java define?

3. What are the built-in streams?

---

1. A stream is an abstraction that either produces or consumes information.
2. Java defines both byte and character streams.
Using the Byte Streams

We will begin our examination of Java’s I/O with the byte streams. As explained, at the top of the byte stream hierarchy are the `InputStream` and `OutputStream` classes. Table 10-3 shows the methods in `InputStream`, and Table 10-4 shows the methods in `OutputStream`. In general, the methods in `InputStream` and `OutputStream` can throw an `IOException` on error. The methods defined by these two abstract classes are available to all of their subclasses. Thus, they form a minimal set of I/O functions that all byte streams will have.

Reading Console Input

Originally, the only way to perform console input was to use a byte stream, and much Java code still uses the byte streams exclusively. Today, you can use byte or character streams. For commercial code, the preferred method of reading console input is to use a character-oriented

<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 the end of the file is encountered.</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 the end of the file is encountered.</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 the end of the file is encountered.</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>
</tbody>
</table>

Table 10-3 The Methods Defined by `InputStream`
Doing so makes your program easier to internationalize and easier to maintain. It is also more convenient to operate directly on characters rather than converting back and forth between characters and bytes. However, for sample programs, simple utility programs for your own use, and applications that deal with raw keyboard input, using the byte streams is acceptable. For this reason, console I/O using byte streams is examined here.

Because `System.in` is an instance of `InputStream`, you automatically have access to the methods defined by `InputStream`. Unfortunately, `InputStream` defines only one input method, `read()`, which reads bytes. There are three versions of `read()`, which are shown here:

```java
int read( ) throws IOException

int read(byte data[ ]) throws IOException

int read(byte data[ ], int start, int max) throws IOException
```

In Module 3 you saw how to use the first version of `read()` to read a single character from the keyboard (from `System.in`). It returns –1 when the end of the stream is encountered. The second version reads bytes from the input stream and puts them into `data` until either the array is full, the end of stream is reached, or an error occurs. It returns the number of bytes read, or –1 when the end of the stream is encountered. The third version reads input into `data` beginning at the location specified by `start`. Up to `max` bytes are stored. It returns the number of bytes read, or –1 when the end of the stream is reached. All throw an `IOException` when an error occurs. When reading from `System.in`, pressing ENTER generates an end-of-stream condition.
Here is a program that demonstrates reading an array of bytes from System.in.

```java
// Read an array of bytes from the keyboard.
import java.io.*;

class ReadBytes {
    public static void main(String args[])
       throws IOException {
        byte data[] = new byte[10];

        System.out.println("Enter some characters.");
        System.in.read(data);
        System.out.print("You entered: ");
        for(int i=0; i < data.length; i++)
           System.out.print((char) data[i]);
    }
}
```

Here is a sample run:

Enter some characters.
Read Bytes
You entered: Read Bytes

Writing Console Output

As is the case with console input, Java originally provided only byte streams for console output. Java 1.1 added character streams. For the most portable code, character streams are recommended. Because System.out is a byte stream, however, byte-based console output is still widely used. In fact, all of the programs in this book up to this point have used it! Thus, it is examined here.

Console output is most easily accomplished with print() and println(), with which you are already familiar. These methods are defined by the class PrintStream (which is the type of the object referenced by System.out). Even though System.out is a byte stream, it is still acceptable to use this stream for simple console output.

Since PrintStream is an output stream derived from OutputStream, it also implements the low-level method write(). Thus, it is possible to write to the console by using write(). The simplest form of write() defined by PrintStream 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 8 bits are written. Here is a short example that uses write( ) to output the character “X” followed by a new line:

```java
// Demonstrate System.out.write().
class WriteDemo {
    public static void main(String args[]) {
        int b;

        b = 'X';
        System.out.write(b); // Write a byte to the screen.
        System.out.write('\n');
    }
}
```

You will not often use write( ) to perform console output (although it might be useful in some situations), since print( ) and println( ) are substantially easier to use.

**Progress Check**

1. What method is used to read a byte from System.in?
2. Other than print( ) and println( ), what method can be used to write to System.out?

---

**Critical Skill**

Reading and Writing Files Using Byte Streams

Java provides a number of classes and methods that allow you to read and write files. Of course, the most common types of files are disk files. In Java, all files are byte-oriented, and Java provides methods to read and write bytes from and to a file. Thus, reading and writing files using byte streams is very common. However, Java allows you to wrap a byte-oriented file stream within a character-based object, which is shown later in this module.

To create a byte stream linked to a file, use FileInputStream or FileOutputStream. To open a file, simply create an object of one of these classes, specifying the name of the file as an argument to the constructor. Once the file is open, you can read from or write to it.
Inputting from a File

A file is opened for input by creating a `FileInputStream` object. Here is its most commonly used constructor.

```java
FileInputStream(String fileName) throws FileNotFoundException
```

Here, `fileName` specifies the name of the file you want to open. If the file does not exist, then `FileNotFoundException` is thrown.

To read from a file, you can use `read()`. The version that we will use is shown here:

```java
int read() throws IOException
```

Each time it is called, `read()` reads a single byte from the file and returns it as an integer value. It returns -1 when the end of the file is encountered. It throws an `IOException` when an error occurs. Thus, this version of `read()` is the same as the one used to read from the console.

When you are done with a file, you should close it by calling `close()`. Its general form 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.

The following program uses `read()` to input and display the contents of a text file, the name of which is specified as a command-line argument. Note the `try/catch` blocks that handle the two errors that might occur when this program is used—the specified file not being found or the user forgetting to include the name of the file. You can use this same approach any time you use command-line arguments.

```java
/* 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[])  
        throws IOException
    {
        int i;
        FileInputStream fin;

        try {
            fin = new FileInputStream(args[0]);
        } catch(FileNotFoundException exc) {
            System.out.println("File Not Found");
            return;
        } catch(ArrayIndexOutOfBoundsException exc) {
            System.out.println("Usage: ShowFile File");
            return;
        }

        // read bytes until EOF is encountered
        do {
            i = fin.read();  \[Read from the file.\]
            if(i != -1) System.out.print((char) i);  \[When i equals -1, the end of the file has been reached.\]
        } while(i != -1);

        fin.close();
    }
}

Ask the Expert

Q: I noticed that read() returns -1 when the end of the file has been reached, but that it does not have a special return value for a file error. Why not?

A: In Java, errors are handled by exceptions. Thus, if read(), or any other I/O method, returns a value, it means that no error has occurred. This is a much cleaner way than handling I/O errors by using special error codes.
Writing to a File

To open a file for output, create a `FileOutputStream` object. Here are its two most commonly used constructors.

FileOutputStream(String `fileName`) throws FileNotFoundException

FileOutputStream(String `fileName`, boolean `append`) throws FileNotFoundException

If the file cannot be created, then `FileNotFoundException` is thrown. In the first form, when an output file is opened, any preexisting file by the same name is destroyed. In the second form, if `append` is `true`, then output is appended to the end of the file. Otherwise, the file is overwritten.

To write to a file, you will use the `write( )` method. 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 8 bits are written to the file. If an error occurs during writing, an `IOException` is thrown.

As you may know, when file output is performed, that output often is not immediately written to the actual physical device. Instead, output is buffered until a sizable chunk of data can be written all at once. This improves the efficiency of the system. For example, disk files are organized by sectors, which might be anywhere from 128 bytes long on up. Output is usually buffered until an entire sector can be written all at once. However, if you want to cause data to be written to the physical device whether or not the buffer is full, you can call `flush( )`, shown here.

```java
void flush() throws IOException
```

An exception is thrown on failure.

Once you are done with an output file, you must close it using `close( )`, 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. It also ensures that any output remaining in a disk buffer is actually written to the disk.
The following example copies a text file. The names of the source and destination files are specified on the command line.

/* Copy a text 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;
        FileOutputStream fout;

        try {
            // open input file
            try {
                fin = new FileInputStream(args[0]);
            } catch (FileNotFoundException exc) {
                System.out.println("Input File Not Found");
                return;
            }

            // open output file
            try {
                fout = new FileOutputStream(args[1]);
            } catch (FileNotFoundException exc) {
                System.out.println("Error Opening Output File");
                return;
            }

            try {
                // copy the bytes
                i = fin.read();
                while (i != -1) {
                    fout.write(i);
                    i = fin.read();
                }
            } catch (IOException exc) {
                System.out.println("I/O error");
                return;
            }
        } catch (ArrayIndexOutOfBoundsException exc) {
            System.out.println("Usage: CopyFile From To");
            return;
        }
    }
}
Progress Check

1. What does read() return when the end of the file is reached?

2. What does flush() do?

CRITICAL SKILL

10.8 Reading and Writing Binary Data

So far, we have just been reading and writing bytes containing ASCII characters, but it is possible—indeed, common—to read and write other types of data. For example, you might want to create a file that contains ints, doubles, or shorts. To read and write binary values of the Java simple types, you will use DataInputStream and DataOutputStream.

DataOutputStream implements the DataOutput interface. This interface defines methods that write all of Java’s simple types to a file. It is important to understand that this data is written using its internal, binary format, not its human-readable text form. The most commonly used output methods for Java’s simple types are shown in Table 10-5. Each throws an IOException on failure.

Here is the constructor for DataOutputStream. Notice that it is built upon an instance of OutputStream.

DataOutputStream(OutputStream outputStream)

1. A −1 is returned by read() when the end of the file is encountered.

2. A call to flush() causes any buffered output to be physically written to the storage device.
Here, `outputStream` is the stream to which data is written. To write output to a file, you can use the object created by `FileOutputStream` for this parameter.

`DataInputStream` implements the `DataInput` interface, which provides methods for reading all of Java’s simple types. These methods are shown in Table 10-6, and each can throw an `IOException`.

`DataInputStream` uses an `InputStream` instance as its foundation, overlaying it with methods that read the various Java data types. Remember that `DataInputStream` reads data in its binary format, not its human-readable form. The constructor for `DataInputStream` is shown here.

```
DataInputStream(InputStream inputStream)
```

<table>
<thead>
<tr>
<th>Output Method</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void writeBoolean(boolean val)</code></td>
<td>Writes the <code>boolean</code> specified by <code>val</code>.</td>
</tr>
<tr>
<td><code>void writeByte(int val)</code></td>
<td>Writes the low-order byte specified by <code>val</code>.</td>
</tr>
<tr>
<td><code>void writeChar(int val)</code></td>
<td>Writes the value specified by <code>val</code> as a character.</td>
</tr>
<tr>
<td><code>void writeDouble(double val)</code></td>
<td>Writes the <code>double</code> specified by <code>val</code>.</td>
</tr>
<tr>
<td><code>void writeFloat(float val)</code></td>
<td>Writes the <code>float</code> specified by <code>val</code>.</td>
</tr>
<tr>
<td><code>void writeInt(int val)</code></td>
<td>Writes the <code>int</code> specified by <code>val</code>.</td>
</tr>
<tr>
<td><code>void writeLong(long val)</code></td>
<td>Writes the <code>long</code> specified by <code>val</code>.</td>
</tr>
<tr>
<td><code>void writeShort(int val)</code></td>
<td>Writes the value specified by <code>val</code> as a <code>short</code>.</td>
</tr>
</tbody>
</table>

**Table 10-5** Commonly Used Output Methods Defined by `DataOutputStream`

<table>
<thead>
<tr>
<th>Input Method</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>boolean readBoolean()</code></td>
<td>Reads a <code>boolean</code></td>
</tr>
<tr>
<td><code>byte readByte()</code></td>
<td>Reads a <code>byte</code></td>
</tr>
<tr>
<td><code>char readChar()</code></td>
<td>Reads a <code>char</code></td>
</tr>
<tr>
<td><code>double readDouble()</code></td>
<td>Reads a <code>double</code></td>
</tr>
<tr>
<td><code>float readFloat()</code></td>
<td>Reads a <code>float</code></td>
</tr>
<tr>
<td><code>int readInt()</code></td>
<td>Reads an <code>int</code></td>
</tr>
<tr>
<td><code>long readLong()</code></td>
<td>Reads a <code>long</code></td>
</tr>
<tr>
<td><code>short readShort()</code></td>
<td>Reads a <code>short</code></td>
</tr>
</tbody>
</table>

**Table 10-6** Commonly Used Input Methods Defined by `DataInputStream`
Here, *inputStream* is the stream that is linked to the instance of *DataInputStream* being created. To read input from a file, you can use the object created by *FileInputStream* for this parameter.

Here is a program that demonstrates *DataOutputStream* and *DataInputStream*. It writes and then reads back various types of data to and from a file.

```java
// Write and then read back binary data.
import java.io.*;

class RWData {
    public static void main(String args[])
        throws IOException {
        DataOutputStream dataOut;
        DataInputStream dataIn;

        int i = 10;
        double d = 1023.56;
        boolean b = true;

        try {
            dataOut = new DataOutputStream(new FileOutputStream("testdata"));
            System.out.println("Writing " + i);
            dataOut.writeInt(i);
            System.out.println("Writing " + d);
            dataOut.writeDouble(d);
            System.out.println("Writing " + b);
            dataOut.writeBoolean(b);
            System.out.println("Writing " + 12.2 * 7.4);
            dataOut.writeDouble(12.2 * 7.4);
        };
        }

        } catch(IOException exc) {
            System.out.println("Cannot open file.");
            return;
        }

        try {
            System.out.println("Writing " + i);
            dataOut.writeInt(i);
            System.out.println("Writing " + d);
            dataOut.writeDouble(d);
            System.out.println("Writing " + b);
            dataOut.writeBoolean(b);
            System.out.println("Writing " + 12.2 * 7.4);
            dataOut.writeDouble(12.2 * 7.4);
        }
        catch(IOException exc) {
            System.out.println("Write error.");
        }
```
dataOut.close();

System.out.println();

// Now, read them back.
try {
    dataIn = new DataInputStream(new FileInputStream("testdata"));
} catch (IOException exc) {
    System.out.println("Cannot open file.");
    return;
}

try {
    i = dataIn.readInt();
    System.out.println("Reading " + i);

    d = dataIn.readDouble();
    System.out.println("Reading " + d);

    b = dataIn.readBoolean();
    System.out.println("Reading " + b);

    d = dataIn.readDouble();
    System.out.println("Reading " + d);
} catch (IOException exc) {
    System.out.println("Read error.");
}

dataIn.close();
}

The output from the program is shown here.

Writing 10
Writing 1023.56
Writing true
Writing 90.28

Reading 10
Reading 1023.56
Reading true
Reading 90.28
Progress Check

1. To write binary data, what type of stream should you use?
2. What method do you call to write a double?
3. What method do you call to read a short?

Project 10-1  A File Comparison Utility

This project develops a simple, yet useful file comparison utility. It works by opening both files to be compared and then reading and comparing each corresponding set of bytes. If a mismatch is found, the files differ. If the end of each file is reached at the same time and if no mismatches have been found, then the files are the same.

Step by Step

1. Create a file called CompFiles.java.
2. Into CompFiles.java, add the following program.

   /*
   * Project 10-1
   * Compare two files.
   *
   * To use this program, specify the names of the files to be compared on the command line.
   *
   * java CompFile FIRST.TXT SECOND.TXT
   */

   import java.io.*;

   class CompFiles {
       public static void main(String args[])
           throws IOException
       {
           // Code here
   
1. To write binary data, use DataOutputStream.
2. To write a double, call writeDouble().
3. To read a short, call readShort().
int i=0, j=0;
FileInputStream f1;
FileInputStream f2;

try {
    // open first file
    try {
        f1 = new FileInputStream(args[0]);
    } catch(FileNotFoundException exc) {
        System.out.println(args[0] + " File Not Found");
        return;
    }

    // open second file
    try {
        f2 = new FileInputStream(args[1]);
    } catch(FileNotFoundException exc) {
        System.out.println(args[1] + " File Not Found");
        return;
    }
}

    try {
        do {
            i = f1.read();
            j = f2.read();
            if(i != j) break;
        } while(i != -1 && j != -1);
    } catch(IOException exc) {
        System.out.println("File Error");
    }

    if(i != j)
        System.out.println("Files differ.");
    else
        System.out.println("Files are the same.");

    f1.close();
    f2.close();
}

(continued)
3. To try CompFiles, first copy CompFiles.java to a file called temp. Then, try this command line

```
java CompFiles CompFiles.java temp
```

The program will report that the files are the same. Next, compare CompFiles.java to CopyFile.java (shown earlier) using this command line:

```
java CompFiles CompFiles.java CopyFile.java
```

These files differ and CompFiles will report this fact.

4. On your own, try enhancing CompFiles with various options. For example, add an option that ignores the case of letters. Another idea is to have CompFiles display the position within the file where the files differ.

---

**CRITICAL SKILL 10.9**

**Random Access Files**

Up to this point, we have been using sequential files, which are files that are accessed in a strictly linear fashion, one byte after another. However, Java also allows you to access the contents of a file in random order. To do this you will use RandomAccessFile, which encapsulates a random-access file. RandomAccessFile is not derived from InputStream or OutputStream. Instead, it implements the interfaces DataInput and DataOutput, which define the basic I/O methods. It also supports positioning requests—that is, you can position the file pointer within the file. The constructor that we will be using is shown here.

```
RandomAccessFile(String fileName, String access)
    throws FileNotFoundException
```

Here, the name of the file is passed in fileName and access determines what type of file access is permitted. If it is “r”, the file can be read but not written. If it is “rw”, the file is opened in read-write mode.

The method seek(), shown here, is used to set the current position of the file pointer within the file:

```
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 read() and write() methods. It also implements the DataInput and DataOutput interfaces, which means that methods to read and write the simple types, such as readInt() and writeDouble(), are available.
Here is an example that demonstrates random access I/O. It writes six doubles to a file and then reads them back in nonsequential order.

```java
// Demonstrate random access files.
import java.io.*;

class RandomAccessDemo {
    public static void main(String args[]) throws IOException {
        double data[] = { 19.4, 10.1, 123.54, 33.0, 87.9, 74.25 };
        double d;
        RandomAccessFile raf;

        try {
            raf = new RandomAccessFile("random.dat", "rw");
        } catch (FileNotFoundException exc) {
            System.out.println("Cannot open file.");
            return ;
        }

        // Write values to the file.
        for(int i=0; i < data.length; i++) {
            try {
                raf.writeDouble(data[i]);
            } catch (IOException exc) {
                System.out.println("Error writing to file.");
                return ;
            }
        }

        try {
            // Now, read back specific values
            raf.seek(0); // seek to first double
            d = raf.readDouble();
            System.out.println("First value is " + d);

            raf.seek(8); // seek to second double
            d = raf.readDouble();
            System.out.println("Second value is " + d);

            raf.seek(8 * 3); // seek to fourth double
            d = raf.readDouble();
            System.out.println("Fourth value is " + d);
        }
    }
}
```

Open random access file.

Use seek() to set file pointer.
System.out.println();

// Now, read every other value.
System.out.println("Here is every other value: ");
for(int i=0; i < data.length; i+=2) {
    raf.seek(8 * i); // seek to ith double
    d = raf.readDouble();
    System.out.print(d + " ");
}
}
catch(IOException exc) {
    System.out.println("Error seeking or reading.");
}

raf.close();
}
}

The output from the program is shown here.

First value is 19.4
Second value is 10.1
Fourth value is 33.0

Here is every other value:
19.4 123.54 87.9

Notice how each value is located. Since each double value is 8 bytes long, each value starts on an 8-byte boundary. Thus, the first value is located at zero, the second begins at byte 8, the third starts at byte 16, and so on. Thus, to read the fourth value, the program seeks to location 24.

Progress Check

1. What class do you use to create a random access file?
2. How do you position the file pointer?

1. To create a random access file, use RandomAccessFile.
2. To position the file pointer, use seek().
Using Java’s Character-Based Streams

As the preceding sections have shown, Java’s byte streams are both powerful and flexible. However, they are not the ideal way to handle character-based I/O. For this purpose, Java defines the character stream classes. At the top of the character stream hierarchy are the abstract classes `Reader` and `Writer`. Table 10-7 shows the methods in `Reader`, and Table 10-8 shows the methods in `Writer`. All of the methods can throw an `IOException` on error. The methods defined by these two abstract classes are available to all of their subclasses. Thus, they form a minimal set of I/O functions that all character streams will have.

<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 <code>IOException</code>.</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 <code>numChars</code> characters are read.</td>
</tr>
<tr>
<td>boolean markSupported( )</td>
<td>Returns <code>true</code> if <code>mark( )/reset( )</code> 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 the end of the file is encountered.</td>
</tr>
<tr>
<td>int read(char buffer[ ])</td>
<td>Attempts to read up to <code>buffer.length</code> characters into <code>buffer</code> and returns the actual number of characters that were successfully read. –1 is returned when the end of the file is encountered.</td>
</tr>
<tr>
<td>abstract int read(char buffer[ ], int offset, int numChars)</td>
<td>Attempts to read up to <code>numChars</code> characters into <code>buffer</code> starting at <code>buffer[offset]</code>, returning the number of characters successfully read. –1 is returned when the end of the file is encountered.</td>
</tr>
<tr>
<td>boolean ready( )</td>
<td>Returns <code>true</code> if the next input request will not wait. Otherwise, it returns <code>false</code>.</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 <code>numChars</code> characters of input, returning the number of characters actually skipped.</td>
</tr>
</tbody>
</table>

Table 10-7  The Methods Defined by `Reader`
Console Input Using Character Streams

For code that will be internationalized, inputting from the console using Java’s character-based streams is a better, more convenient way to read characters from the keyboard than is using the byte streams. However, since System.in is a byte stream, you will need to wrap System.in inside some type of Reader. The best class for reading console input is BufferedReader, which supports a buffered input stream. However, you cannot construct a BufferedReader directly from System.in. Instead, you must first convert it into a character stream. To do this, you will use InputStreamReader, which converts bytes to characters. To obtain an InputStreamReader object that is linked to System.in, use the constructor shown here:

InputStreamReader(InputStream inputStream)

Since System.in refers to an object of type InputStream, it can be used for inputStream.

Next, using the object produced by InputStreamReader, construct a BufferedReader using the constructor shown here:

BufferedReader(Reader inputReader)
Here, `inputReader` is the stream that is linked to the instance of `BufferedReader` being created. Putting it all together, the following line of code creates a `BufferedReader` that is connected to the keyboard.

```java
BufferedReader br = new BufferedReader(new InputStreamReader(System.in));
```

After this statement executes, `br` will be a character-based stream that is linked to the console through `System.in`.

### Reading Characters

Characters can be read from `System.in` using the `read()` method defined by `BufferedReader` in much the same way as they were read using byte streams. `BufferedReader` defines the following versions of `read()`:

- `int read() throws IOException`
- `int read(char data[]) throws IOException`
- `int read(char data[], int start, int max) throws IOException`

The first version of `read()` reads a single Unicode character. It returns `-1` when the end of the stream is reached. The second version reads characters from the input stream and puts them into `data` until either the array is full, the end of file is reached, or an error occurs. It returns the number of characters read or `-1` at end of stream. The third version reads input into `data` beginning at the location specified by `start`. Up to `max` characters are stored. It returns the number of characters read or `-1` when the end of the stream is encountered. All throw an `IOException` on error. When reading from `System.in`, pressing ENTER generates an end-of-stream condition.

The following program demonstrates `read()` by reading characters from the console until the user types a period.

```java
// Use a BufferedReader to read characters from the console.
import java.io.*;

class ReadChars {
   public static void main(String args[])
      throws IOException
   {
      char c;
      BufferedReader br = new BufferedReader(new InputStreamReader(System.in));
      
      Create BufferedReader linked to System.in.
```
System.out.println("Enter characters, period to quit.");

// read characters
do {
    c = (char) br.read();
    System.out.println(c);
} while(c != '.');
}

Here is a sample run.

Enter characters, period to quit.
One Two.
O
n
T
w
O
.

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

It returns a String object that contains the characters read. It returns null if an attempt is made to read when at the end of the stream.

The following program demonstrates BufferedReader and the readLine( ) method. The program reads and displays lines of text until you enter the word “stop”.

// Read a string from console using a BufferedReader.
import java.io.*;

class ReadLines {
    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(); /* Use readLine() from BufferedReader to read a line of text.
    System.out.println(str);
} while(!str.equals("stop"));

Console Output Using Character Streams

While it is still permissible to use System.out to write to the console under Java, its use is recommended mostly for debugging purposes or for sample programs such as those found in this book. For real-world programs, the preferred method of writing to the console when using Java is through a PrintWriter stream. PrintWriter is one of the character-based classes. As explained, using a character-based class for console output makes it easier to internationalize your program.

PrintWriter defines several constructors. The one we will use is shown here:

PrintWriter(OutputStream outputStream, boolean flushOnNewline)

Here, outputStream is an object of type OutputStream and flushOnNewline controls whether Java flushes the output stream every time a println() method is called. If flushOnNewline is true, flushing automatically takes place. If false, flushing is not automatic.

PrintWriter supports the print() and println() methods for all types including Object. Thus, you can use these methods in just the same way as they have been used with System.out. If an argument is not a simple type, the PrintWriter methods will call the object’s toString() method and then print out the result.

To write to the console using a PrintWriter, specify System.out for the output stream and flush the stream after each call to println(). For example, this line of code creates a PrintWriter that is connected to console output.

PrintWriter pw = new PrintWriter(System.out, true);

The following application illustrates using a PrintWriter to handle console output.

// Demonstrate PrintWriter.
import java.io.*;

public class PrintWriterDemo {
    public static void main(String args[]) {
        PrintWriter pw = new PrintWriter(System.out, true);
        int i = 10;
        double d = 123.67;
pw.println("Using a PrintWriter.");
pw.println(i);
pw.println(d);

pw.println(i + " + " + d + " is " + i+d);
}
}

The output from this program is:

Using a PrintWriter.
10
123.67
10 + 123.67 is 10123.67

Remember that 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 will make your real-world applications easier to internationalize. Since no advantage is to be gained by using a PrintWriter in the sample programs shown in this book, for convenience we will continue to use System.out to write to the console.

Progress Check

1. What classes top the character-based stream classes?

2. To read from the console, you will open what type of reader?

3. To write to the console, you will open what type of writer?

1. At the top of the character-based stream, classes are Reader and Writer.
2. To read from the console, open a BufferedReader.
3. To write to the console, open a PrintWriter.
File I/O Using Character Streams

Although byte-oriented file handling is the most common, it is possible to use character-based streams for this purpose. The advantage to the character streams is that they operate directly on Unicode characters. Thus, if you want to store Unicode text, the character streams are certainly your best option. In general, to perform character-based file I/O, you will use the FileReader and FileWriter classes.

Using a FileWriter

FileWriter creates a Writer that you can use to write to a file. Its most commonly used constructors are shown here:

FileWriter(String fileName) throws IOException

FileWriter(String fileName, boolean append) throws IOException

Here, fileName is the full path name of a file. If append is true, then output is appended to the end of the file. Otherwise, the file is overwritten. Either throws an IOException on failure. FileWriter is derived from OutputStreamWriter and Writer. Thus, it has access to the methods defined by these classes.

Here is a simple key-to-disk utility that reads lines of text entered at the keyboard and writes them to a file called “test.txt.” Text is read until the user enters the word “stop.” It uses a FileWriter to output to the file.

/* A simple key-to-disk utility that
   demonstrates a FileWriter. */

import java.io.*;

class KtoD {
   public static void main(String args[])
      throws IOException {

      String str;
      FileWriter fw;
      BufferedReader br =
         new BufferedReader(
            new InputStreamReader(System.in));
try {
    fw = new FileWriter("test.txt");  // Create a FileWriter.
}
catch(IOException exc) {
    System.out.println("Cannot open file.");
    return;
}

System.out.println("Enter text ('stop' to quit).");
do {
    System.out.print(":\	");
    str = br.readLine();
    if(str.compareTo("stop") == 0) break;
    str = str + "\r\n"; // add newline
    fw.write(str);  // Write strings to the file.
} while(str.compareTo("stop") != 0);

fw.close();

Using a FileReader

The FileReader class creates a Reader that you can use to read the contents of a file. Its most commonly used constructor is shown here:

FileReader(String fileName) throws FileNotFoundException

Here, fileName is the full path name of a file. It throws a FileNotFoundException if the file does not exist. FileReader is derived from InputStreamReader and Reader. Thus, it has access to the methods defined by these classes.

The following program creates a simple disk-to-screen utility that reads a text file called “test.txt” and displays its contents on the screen. Thus, it is the complement of the key-to-disk utility shown in the previous section.

/* A simple disk-to-screen utility that demonstrates a FileReader. */

import java.io.*;

class DtoS {
    public static void main(String args[]) throws Exception {

FileReader fr = new FileReader("test.txt");
BufferedReader br = new BufferedReader(fr);
String s;
while((s = br.readLine()) != null) {
    System.out.println(s);
}
fr.close();
}
}

In this example, notice that the FileReader is wrapped in a BufferedReader. This gives it access to readLine().

Ask the Expert

Q: I have heard that a new I/O system was recently added to Java. Can you tell me about it?

A: In 2002, Java 2, version 1.4 added a new way to handle I/O operations. Called the new I/O APIs, it is one of the more interesting additions that Sun included in the 1.4 release because it supports a channel-based approach to I/O operations. The new I/O classes are contained in java.nio and its subordinate packages, such as java.nio.channels and java.nio.charset.

The new I/O system (NIO) 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 new I/O 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.

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. 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 most applicable to socket-backed channels.

It is important to understand that the new I/O subsystem is not intended to replace the I/O classes found in java.io, which are discussed in this module. Instead, the NIO classes are designed to supplement the standard I/O system, offering an alternative approach, which can be beneficial in some circumstances.
Progress Check

1. What class is used to read characters from a file?
2. What class is used to write characters to a file?

Using Java’s Type Wrappers to Convert Numeric Strings

Before leaving the topic of I/O, we will examine a technique useful when reading numeric strings. As you know, Java’s `println()` method provides a convenient way to output various types of data to the console, including numeric values of the built-in types, such as `int` and `double`. Thus, `println()` automatically converts numeric values into their human-readable form. However, Java does not provide an input method that reads and converts strings containing numeric values into their internal, binary format. For example, there is no input method that lets you enter at the keyboard a string such as “100” and have it automatically converted into its corresponding binary value that is able to be stored in an `int` variable. To accomplish this task, you will need to use one of Java’s type wrappers.

Java’s type wrappers are classes that encapsulate, or wrap, the simple types. Type wrappers are needed because the simple types are not objects. This limits their use to some extent. For example, a simple type cannot be passed by reference. To address this kind of need, Java provides classes that correspond to each of the simple types.

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 simple types into Java’s object hierarchy. As a side benefit, the numeric wrappers also define methods that convert a numeric string into its corresponding binary equivalent. These conversion methods are shown here. Each returns a binary value that corresponds to the string.

<table>
<thead>
<tr>
<th>Wrapper</th>
<th>Conversion Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double</td>
<td>static double parseDouble(String str) throws NumberFormatException</td>
</tr>
<tr>
<td>Float</td>
<td>static float parseFloat(String str) throws NumberFormatException</td>
</tr>
</tbody>
</table>

1. To read characters, use a `FileReader`.
2. To write characters, use a `FileWriter`.
Using I/O

<table>
<thead>
<tr>
<th>Wrapper</th>
<th>Conversion Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long</td>
<td>static long parseLong(String str) throws NumberFormatException</td>
</tr>
<tr>
<td>Integer</td>
<td>static int parseInt(String str) throws NumberFormatException</td>
</tr>
<tr>
<td>Short</td>
<td>static short parseShort(String str) throws NumberFormatException</td>
</tr>
<tr>
<td>Byte</td>
<td>static byte parseByte(String str) throws NumberFormatException</td>
</tr>
</tbody>
</table>

The integer wrappers also offer a second parsing method that allows you to specify the radix.

The parsing methods give us an easy way to convert a numeric value, read as a string from the keyboard or a text file, into its proper internal format. For example, the following program demonstrates `parseInt()` and `parseDouble()`. It averages a list of numbers entered by the user. It first asks the user for the number of values to be averaged. It then reads that number using `readLine()` and uses `parseInt()` to convert the string into an integer. Next, it inputs the values, using `parseDouble()` to convert the strings into their `double` equivalents.

```java
import java.io.*;

class AvgNums {
    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 n;
        double sum = 0.0;
        double avg, t;

        System.out.print("How many numbers will you enter: ");
        str = br.readLine();
        try {
            n = Integer.parseInt(str);  // Convert string to int.
        } catch(NumberFormatException exc) {
            System.out.println("Invalid format");
            n = 0;
        }

        // input n numbers
        for (int i = 0; i < n; i++) {
            System.out.print("Enter number ");
            t = Double.parseDouble(br.readLine());
            sum += t;
        }
        System.out.println("Average = "+sum/n);
    }
}
```
System.out.println("Enter " + n + " values.");
for(int i=0; i < n ; i++)  {
    System.out.print(": ");
    str = br.readLine();
    try {
        t = Double.parseDouble(str);
    } catch(NumberFormatException exc) {
        System.out.println("Invalid format");
        t = 0.0;
    }
    sum += t;
}
avg = sum / n;
System.out.println("Average is " + avg);
}

Here is a sample run.

How many numbers will you enter: 5
Enter 5 values.
: 1.1
: 2.2
: 3.3
: 4.4
: 5.5
Average is 3.3

Ask the Expert

Q: What else can the simple type wrapper classes do?

A: The simple type wrappers provide a number of methods that help integrate the simple types into the object hierarchy. For example, various storage mechanisms provided by the Java library, including maps, lists, and sets, work only with objects. Thus, to store an int, for example, in a list, it must be wrapped in an object. Also, all type wrappers have a method called compareTo(), which compares the value contained within the wrapper; equals(), which tests two values for equality; and methods that return the simple-type value of the object in various forms.
**Project 10-2 Creating a Disk-Based Help System**

In Project 4-1 you created a Help class that displayed information about Java’s control statements. In that implementation, the help information was stored within the class itself, and the user selected help from a menu of numbered options. Although this approach was fully functional, it is certainly not the ideal way of creating a Help system. For example, to add to or change the help information, the source code of the program needed to be modified. Also, the selection of the topic by number rather than by name is tedious, and is not suitable for long lists of topics. Here, we will remedy this shortcoming by creating a disk-based Help system.

The disk-based Help system stores help information in a help file. The help file is a standard text file that can be changed or expanded at will, without changing the Help program. The user obtains help about a topic by typing in its name. The Help system searches the help file for the topic. If it is found, information about the topic is displayed.

**Step by Step**

1. Create the help file that will be used by the Help system. The help file is a standard text file that is organized like this:

   ```
   #topic-name1
   topic info
   #topic-name2
   topic info
   .
   .
   .
   #topic-nameN
   topic info
   ```

   The name of each topic must be preceded by a #, and the topic name must be on a line of its own. Preceding each topic name with a # allows the program to quickly find the start of each topic. After the topic name are any number of information lines about the topic. However, there must be a blank line between the end of one topic’s information and the start of the next topic. Also, there must be no trailing spaces at the end of any lines.

   *(continued)*
Here is a simple help file that you can use to try the disk-based Help system. It stores information about Java’s control statements.

```java
#include
if(condition) statement;
else statement;

switch
switch(expression) {
    case constant:
        statement sequence
        break;
    // ...
}

for
for(init; condition; iteration) statement;

while
while(condition) statement;

do
do { 
    statement;
} while (condition);

break
break; or break label;

continue
continue; or continue label;
```

Call this file `helpfile.txt`.

2. Create a file called `FileHelp.java`.

3. Begin creating the new `Help` class with these lines of code.

```java
class Help {
    String helpfile; // name of help file

    Help(String fname) {
        helpfile = fname;
    }
```
The name of the help file is passed to the `Help` constructor and stored in the instance variable `helpfile`. Since each instance of `Help` will have its own copy of `helpfile`, each instance can use a different file. Thus, you can create different sets of help files for different sets of topics.

4. Add the `helpon( )` method shown here to the `Help` class. This method retrieves help on the specified topic.

```java
// Display help on a topic.
boolean helpon(String what) {
    FileReader fr;
    BufferedReader helpRdr;
    int ch;
    String topic, info;

    try {
        fr = new FileReader(helpfile);
        helpRdr = new BufferedReader(fr);
    }
    catch(FileNotFoundException exc) {
        System.out.println("Help file not found.");
        return false;
    }
    catch(IOException exc) {
        System.out.println("Cannot open file.");
        return false;
    }

    try {
        do {
            // read characters until a # is found
            ch = helpRdr.read();

            // now, see if topics match
            if(ch == '#') {
                topic = helpRdr.readLine();
                if(what.compareTo(topic) == 0) { // found topic
                    do {
                        info = helpRdr.readLine();
                        if(info != null) System.out.println(info);
                    } while((info != null) &&
                        (info.compareTo("") != 0));
                }
            }
        } while(ch != -1);
    }
```

(continued)
The first thing to notice is that `helpon()` handles all possible I/O exceptions itself. It does not even include a `throws` clause. By handling its own exceptions, it prevents this burden from being passed on to all code that uses it. Thus, other code can simply call `helpon()` without having to wrap that call in a `try/catch` block.

The help file is opened using a `FileReader` that is wrapped in a `BufferedReader`. Since the help file contains text, using a character stream allows the Help system to be more efficiently internationalized.

The `helpon()` method works like this. A string containing the name of the topic is passed in the `what` parameter. The help file is then opened. Then, the file is searched, looking for a match between `what` and a topic in the file. Remember, in the file, each topic is preceded by a #, so the search loop scans the file for #s. When it finds one, it then checks to see if the topic following that # matches the one passed in `what`. If it does, the information associated with that topic is displayed. If a match is found, `helpon()` returns `true`. Otherwise, it returns `false`.

5. The `Help` class also provides a method called `getSelection()`. It prompts the user for a topic and returns the topic string entered by the user.

```java
// Get a Help topic.
String getSelection() {
    String topic = "";
```
BufferedReader br = new BufferedReader(
    new InputStreamReader(System.in));

System.out.print("Enter topic: ");
try {
    topic = br.readLine();
} catch (IOException exc) {
    System.out.println("Error reading console.");
} return topic;

This method creates a BufferedReader attached to System.in. It then prompts for the name of a topic, reads the topic, and returns it to the caller.

6. The entire disk-based Help system is shown here.

/*
   Project 10-2
   
   A help program that uses a disk file to store help information.
   */

import java.io.*;

/* The Help class opens a help file, searches for a topic, and then displays the information associated with that topic. Notice that it handles all I/O exceptions itself, avoiding the need for calling code to do so. */
class Help {
    String helpfile; // name of help file

    Help(String fname) {
        helpfile = fname;
    }

    // Display help on a topic.
    boolean helpon(String what) {
        FileReader fr;
        BufferedReader helpRdr;
        int ch;
        String topic, info;
try {
    fr = new FileReader(helpfile);
    helpRdr = new BufferedReader(fr);
}
catch(FileNotFoundException exc) {
    System.out.println("Help file not found.");
    return false;
}
catch(IOException exc) {
    System.out.println("Cannot open file.");
    return false;
}

try {
    do {
        // read characters until a # is found
        ch = helpRdr.read();

        // now, see if topics match
        if(ch == '#') {
            topic = helpRdr.readLine();
            if(what.compareTo(topic) == 0) { // found topic
                do {
                    info = helpRdr.readLine();
                    System.out.println(info);
                } while((info != null) &&
                    (info.compareTo("") != 0));
                return true;
            }
        }
    } while(ch != -1);
}
catch(IOException exc) {
    System.out.println("File error.");
    try {
        helpRdr.close();
    }
    catch(IOException exc2) {
        System.out.println("Error closing file.");
    }
    return false;
}
try {
helpRdr.close();
}
catch(IOException exc) {
    System.out.println("Error closing file.");
}
return false; // topic not found

// Get a Help topic.
String getSelection() {
    String topic = "";

    BufferedReader br = new BufferedReader(
        new InputStreamReader(System.in));

    System.out.print("Enter topic: ");
    try {
        topic = br.readLine();
    } catch(IOException exc) {
        System.out.println("Error reading console.");
    }
    return topic;
}

// Demonstrate the file-based Help system.
class FileHelp {
    public static void main(String args[]) {
        Help hlpobj = new Help("helpfile.txt");
        String topic;

        System.out.println("Try the help system. " +
                           "Enter 'stop' to end.");
        do {
            topic = hlpobj.getSelection();

            if(!hlpobj.helpon(topic))
                System.out.println("Topic not found.
            ");
        } while(topic.compareTo("stop") != 0);
    }
}
Module 10 Mastery Check

1. Why does Java define both byte and character streams?

2. Even though console input and output is text-based, why does Java still use byte streams for this purpose?

3. Show how to open a file for reading bytes.

4. Show how to open a file for reading characters.

5. Show how to open a file for random access I/O.

6. How do you convert a numeric string such as “123.23” into its binary equivalent?

7. Write a program that copies a text file. In the process, have it convert all spaces into hyphens. Use the byte stream file classes.

8. Rewrite the program described in question 7 so that it uses the character stream classes.

9. What type of stream is `System.in`?

10. What does the `read()` method of `InputStream` return when the end of the stream is reached?

11. What type of stream is used to read binary data?

12. `Reader` and `Writer` are at the top of the ____________ class hierarchies.
Module 11

Multithreaded Programming

CRITICAL SKILLS

11.1 Understand multithreading fundamentals
11.2 Know the Thread class and the Runnable interface
11.3 Create a thread
11.4 Create multiple threads
11.5 Determine when a thread ends
11.6 Use thread priorities
11.7 Understand thread synchronization
11.8 Use synchronized methods
11.9 Use synchronized blocks
11.10 Communicate between threads
11.11 Suspend, resume, and stop threads
Although Java contains many innovative features, one of its most exciting is its 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.

**Multithreading Fundamentals**

There are two distinct types of multitasking: process-based and thread-based. It is important to understand the difference between the two. 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, it is process-based multitasking that allows you to run the Java compiler at the same time you are using a text editor or browsing the Internet. 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 at once. For instance, a text editor can be formatting text at the same time that it is printing, as long as these two actions are being performed by two separate threads. Although Java programs make use of process-based multitasking environments, process-based multitasking is not under the control of Java. Multithreaded multitasking is.

The principal advantage of multithreading is that it enables you to write very efficient programs because it lets you utilize the idle time that is present in most programs. As you probably know, most I/O devices, whether they be network ports, disk drives, or the keyboard, are much slower than the CPU. Thus, a program will often spend a majority of its execution time waiting to send or receive information to or from a device. By using multithreading, your program can execute another task during this idle time. For example, while one part of your program is sending a file over the Internet, another part can be reading keyboard input, and still another can be buffering the next block of data to send.

A thread can be in one of several states. It can be **running**. It can be **ready to run** as soon as it gets CPU time. A running thread can be **suspended**, which is a temporary halt to its execution. It can later be **resumed**. A thread can be **blocked** when waiting for a resource. A thread can be **terminated**, in which case its execution ends and cannot be resumed.

Along with thread-based multitasking comes the need for a special type of feature called **synchronization**, which allows the execution of threads to be coordinated in certain well-defined ways. Java has a complete subsystem devoted to synchronization, and its key features are also described here.

If you have programmed for operating systems such as Windows 98 or Windows 2000, then you are already familiar with multithreaded programming. However, the fact that Java manages threads through language elements makes multithreading especially convenient. Many of the details are handled for you.
The Thread Class and Runnable Interface

Java’s multithreading system is built upon the `Thread` class and its companion interface, `Runnable`. `Thread` encapsulates a thread of execution. 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. Here are some of the more commonly used ones (we will be looking at these more closely as they are used):

<table>
<thead>
<tr>
<th>Method</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>final String getName( )</td>
<td>Obtains a thread’s name.</td>
</tr>
<tr>
<td>final int getPriority( )</td>
<td>Obtains a thread’s priority.</td>
</tr>
<tr>
<td>final boolean isAlive( )</td>
<td>Determines whether a thread is still running.</td>
</tr>
<tr>
<td>final void join( )</td>
<td>Waits for a thread to terminate.</td>
</tr>
<tr>
<td>void run( )</td>
<td>Entry point for the thread.</td>
</tr>
<tr>
<td>static void sleep(long milliseconds)</td>
<td>Suspends a thread for a specified period of milliseconds.</td>
</tr>
<tr>
<td>void start( )</td>
<td>Starts a thread by calling its <code>run()</code> method.</td>
</tr>
</tbody>
</table>

All processes have at least one thread of execution, which is usually called the `main thread`, because it is the one that is executed when your program begins. Thus, the main thread is the thread that all of the preceding example programs in the book have been using. From the main thread, you can create other threads.

### Progress Check

1. What is the difference between process-based multitasking and thread-based multitasking?
2. In what states can a thread exist?
3. What class encapsulates a thread?

---

1. Process-based multitasking is used to run two or more programs concurrently. Thread-based multitasking, called *multithreading*, is used to run pieces of one program concurrently.
2. The thread states are `running`, `ready-to-run`, `suspended`, `blocked`, and `terminated`. When a suspended thread is restarted, it is said to be `resumed`.
3. `Thread`. 
Creating a Thread

You create a thread by instantiating an object of type `Thread`. The `Thread` class encapsulates an object that is runnable. As mentioned, Java defines two ways in which you can create a runnable object:

- You can implement the `Runnable` interface.
- You can extend the `Thread` class.

Most of the examples in this module will use the approach that implements `Runnable`. However, Project 11-1 shows how to implement a thread by extending `Thread`. Remember: Both approaches still use the `Thread` class to instantiate, access, and control the thread. The only difference is how a thread-enabled class is created.

The `Runnable` interface abstracts a unit of executable code. You can construct a thread on any object that implements the `Runnable` interface. `Runnable` defines only one 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. 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 have created a class that implements `Runnable`, you will instantiate an object of type `Thread` on an object of that class. `Thread` defines several constructors. The one that we will use first is shown here:

```java
Thread(Runnable threadOb)
```

In this constructor, `threadOb` is an instance of a class that implements the `Runnable` interface. This defines where execution of the thread will begin.

Once created, the new thread will not start running until you call its `start()` method, which is declared within `Thread`. In essence, `start()` executes a call to `run()`. The `start()` method is shown here:

```java
void start()
```

Here is an example that creates a new thread and starts it running:

```java
// Create a thread by implementing Runnable.

class MyThread implements Runnable {  
  Objects of MyThread can be run in their own threads because MyThread implements Runnable.
}
int count;
String thrdName;

MyThread(String name) {
    count = 0;
    thrdName = name;
}

// Entry point of thread.
public void run() { >> Threads start executing here.
    System.out.println(thrdName + " starting.");
    try {
        do {
            Thread.sleep(500);
            System.out.println("In " + thrdName + ", count is " + count);
            count++;
        } while(count < 10);
    } catch(InterruptedException exc) {
        System.out.println(thrdName + " interrupted. ");
    }
    System.out.println(thrdName + " terminating.");
}

class UseThreads {
    public static void main(String args[]) {
        System.out.println("Main thread starting.");

        // First, construct a MyThread object.
        MyThread mt = new MyThread("Child #1"); >> Create a runnable object.

        // Next, construct a thread from that object.
        Thread newThrd = new Thread(mt); >> Construct a thread on that object.

        // Finally, start execution of the thread.
        newThrd.start(); >> Start running the thread.

        do {
            System.out.print(".");
            try {
                Thread.sleep(100);
            } catch(InterruptedException exc) {
                System.out.println("Main thread interrupted.");
            }
        }
Let's look closely at this program. First, `MyThread` implements `Runnable`. This means that an object of type `MyThread` is suitable for use as a thread and can be passed to the `Thread` constructor.

Inside `run()`, a loop is established that counts from 0 to 9. Notice the call to `sleep()`. 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 can throw an `InterruptedException`. Thus, calls to it must be wrapped in a `try/catch` block. The `sleep()` method also has a second form, which allows you to specify the period in terms of milliseconds and nanoseconds if you need that level of precision.

Inside `main()`, a new `Thread` object is created by the following sequence of statements:

```java
// First, construct a MyThread object.
MyThread mt = new MyThread("Child #1");

// Next, construct a thread from that object.
Thread newThrd = new Thread(mt);

// Finally, start execution of the thread.
newThrd.start();
```

As the comments suggest, first an object of `MyThread` is created. This object is then used to construct a `Thread` object. This is possible because `MyThread` implements `Runnable`. Finally, execution of the new thread is started by calling `start()`. This causes the child thread’s `run()` method to begin. After calling `start()`, execution returns to `main()`, and it enters `main()`’s `do` loop. Both threads continue running, sharing the CPU, until their loops finish. The output produced by this program is as follows. Because of differences between computing environments, the precise output that you see may differ from that shown here.

Main thread starting.
.Child #1 starting.
....In Child #1, count is 0
....In Child #1, count is 1
....In Child #1, count is 2
In Child #1, count is 3
In Child #1, count is 4
In Child #1, count is 5
In Child #1, count is 6
In Child #1, count is 7
In Child #1, count is 8
In Child #1, count is 9
Child #1 terminating.
Main thread ending.

In a multithreaded program, you often will want the main thread to be the last thread to finish running. Technically, a program continues to run until all of its threads have ended. Thus, having the main thread finish last is not a requirement. It is, however, good practice to follow—especially when you are first learning about multithreaded programs. The preceding program ensures that the main thread will finish last, because the do loop stops when count equals 10. Since count will equal 10 only after newThrd has terminated, the main thread finishes last. Later in this module, you will see a better way for one thread to wait until another finishes.

Some Simple Improvements
While the preceding program is perfectly valid, some simple improvements can be made that will make it more efficient and easier to use. First, it is possible to have a thread begin execution as soon as it is created. In the case of MyThread, this is done by instantiating a Thread object inside MyThread’s constructor. Second, there is no need for MyThread to store the name of the thread since it is possible to give a name to a thread when it is created. To do so, use this version of Thread’s constructor.

Thread(Runnable threadOb, String name)

Here, name becomes the name of the thread.

Ask the Expert

Q: Why do you recommend that the main thread be the last to finish?

A: In older Java run-time systems, if the main thread finished before a child thread had completed, there was a possibility that the Java run-time system would “hang.” This problem is not exhibited by the modern Java run-time systems to which this author has access. However, since this behavior was exhibited by some older Java run-time systems, it seems better to be safe rather than sorry since you don’t always know the environment in which your program may run. Also, as you will see, it is trivially easy for the main thread to wait until the child threads have completed.
You can obtain the name of a thread by calling `getName()` defined by `Thread`. Its general form is shown here:

```java
final String getName()
```

Although not needed by the following program, you can set the name of a thread after it is created by using `setName()`, which is shown here:

```java
final void setName(String threadName)
```

Here, `threadName` specifies the name of the thread.

Here is the improved version of the preceding program:

```java
// Improved MyThread.

class MyThread implements Runnable {
    int count;
    Thread thrd; // A reference to the thread is stored in thrd.

    // Construct a new thread.
    MyThread(String name) {
        thrd = new Thread(this, name); // The thread is named when it is created.
        count = 0;
        thrd.start(); // start the thread
    }

    // Begin execution of new thread.
    public void run() {
        System.out.println(thrd.getName() + " starting.");
        try {
            do {
                Thread.sleep(500);
                System.out.println("In " + thrd.getName() + ", count is " + count);
                count++;
            } while(count < 10);
        } catch(InterruptedException exc) {
            System.out.println(thrd.getName() + " interrupted.");
        }
        System.out.println(thrd.getName() + " terminating.");
    }
}

class UseThreadsImproved {
    public static void main(String args[]) {
```
System.out.println("Main thread starting.");

MyThread mt = new MyThread("Child #1");

do {
    System.out.print(".");
    try {
        Thread.sleep(100);
    }
    catch(InterruptedException exc) {
        System.out.println("Main thread interrupted.");
    }
} while (mt.count != 10);

System.out.println("Main thread ending.");

This version produces the same output as before. Notice that the thread is stored in thrd inside MyThread.

Progress Check

1. In what two ways can you create a class that can act as a thread?
2. What is the purpose of the run() method defined by Runnable?
3. What does the start() method defined by Thread do?

Project 11-1 Extending Thread

Implementing Runnable is one way to create a class that can instantiate thread objects. Extending Thread is the other. In this project, you will see how to extend Thread by creating a program functionally identical to the UseThreadsImproved program.

(continued)
When a class extends `Thread`, it must override the `run()` method, which is the entry point for the new thread. It must also call `start()` to begin execution of the new thread. It is possible to override other `Thread` methods, but doing so is not required.

**Step by Step**

1. Create a file called `ExtendThread.java`. Into this file, copy the code from the second threading example (`UseThreadsImproved.java`).

2. Change the declaration of `MyThread` so that it extends `Thread` rather than implementing `Runnable`, as shown here.
   ```java
   class MyThread extends Thread {
   }
   ``

3. Remove this line:
   ```java
   Thread thrd;
   ``
   The `thrd` variable is no longer needed since `MyThread` includes an instance of `Thread` and can refer to itself.

4. Change the `MyThread` constructor so that it looks like this:
   ```java
   // Construct a new thread.
   MyThread(String name) {
       super(name); // name thread
       count = 0;
       start(); // start the thread
   }
   ``
   As you can see, first `super` is used to call this version of `Thread`’s constructor:
   ```java
   Thread(String name);
   ``
   Here, `name` is the name of the thread. The object that will be run is the invoking thread, which in this case is the thread that is being created.

5. Change `run()` so it calls `getName()` directly, without qualifying it with the `thrd` variable. It should look like this:
   ```java
   // Begin execution of new thread.
   public void run() {
       System.out.println(getName() + " starting.");
       try {
           do {
               Thread.sleep(500);
               System.out.println("In " + getName() + " count is " + count);
           } while (count < 10);
       } catch (InterruptedException ie) {
           System.out.println("Thread interrupted.");
       }
   }
   ```
count++;  
} while(count < 10);
}
catch(InterruptedException exc) {
    System.out.println(getName() + " interrupted.");
}
System.out.println(getName() + " terminating.");

6. Here is the completed program that now extends Thread rather than implementing Runnable. The output is the same as before.

/*
Project 11-1

   Extend Thread.
*/
class MyThread extends Thread {
    int count;

    // Construct a new thread.
    MyThread(String name) {
        super(name); // name thread
        count = 0;
        start(); // start the thread
    }

    // Begin execution of new thread.
    public void run() {
        System.out.println(getName() + " starting.");
        try {
            do {
                Thread.sleep(500);
                System.out.println("In " + getName() + ", count is " + count);
                count++;
            } while(count < 10);
        }
        catch(InterruptedException exc) {
            System.out.println(getName() + " interrupted.");
        }
        System.out.println(getName() + " terminating.");
    }
}

class ExtendThread {

(continued)
public static void main(String args[]) {
    System.out.println("Main thread starting.");

    MyThread mt = new MyThread("Child #1");

    do {
        System.out.print(.);
        try {
            Thread.sleep(100);
        } catch(InterruptedException exc) {
            System.out.println("Main thread interrupted.");
        }
    } while (mt.count != 10);

    System.out.println("Main thread ending.");
}

CRITICAL SKILL

11.4 Creating Multiple Threads

The preceding examples have created only 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 MyThread implements Runnable {
    int count;
    Thread thrd;

    // Construct a new thread.
    MyThread(String name) {
        thrd = new Thread(this, name);
        count = 0;
        thrd.start(); // start the thread
    }

    // Begin execution of new thread.
    public void run() {
        System.out.println(thrd.getName() + " starting.");
        try {
            do {
                Thread.sleep(500);
                System.out.println("In " + thrd.getName() + ", count is " + count);
            }
            catch(InterruptedException exc) {
                System.out.println("Main thread interrupted.");
            }
        } while (mt.count != 10);
    }
}
count++;
} while(count < 10);
}
catch(InterruptedException exc) {
    System.out.println(thrd.getName() + " interrupted.");
}
System.out.println(thrd.getName() + " terminating.");
}
}

class MoreThreads {
    public static void main(String args[]) {
        System.out.println("Main thread starting.");

        MyThread mt1 = new MyThread("Child #1");
        MyThread mt2 = new MyThread("Child #2");
        MyThread mt3 = new MyThread("Child #3");

        do {
            System.out.print(".");
            try {
                Thread.sleep(100);
            } catch(InterruptedException exc) {
                System.out.println("Main thread interrupted.");
            }
        } while (mt1.count < 10 ||
                     mt2.count < 10 ||
                     mt3.count < 10);

        System.out.println("Main thread ending.");
    }
}

Ask the Expert

Q: Why does Java have two ways to create child threads (by extending Thread or implementing Runnable) and which approach is better?

A: 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. Some Java programmers feel that classes should be extended only when they are being enhanced or modified in some way. So, if you will not be overriding any of Thread’s other methods, it is probably best to simply implement Runnable. This is, of course, up to you.
Sample output from this program follows. (The output you see may differ slightly.)

Main thread starting.
  .Child #1 starting.
Child #2 starting.
Child #3 starting.
  .....In Child #1, count is 0
In Child #2, count is 0
In Child #3, count is 0
  .....In Child #1, count is 1
In Child #2, count is 1
In Child #3, count is 1
  .....In Child #1, count is 2
In Child #2, count is 2
In Child #3, count is 2
  .....In Child #1, count is 3
In Child #2, count is 3
In Child #3, count is 3
  .....In Child #1, count is 4
In Child #2, count is 4
In Child #3, count is 4
  .....In Child #1, count is 5
In Child #2, count is 5
In Child #3, count is 5
  .....In Child #1, count is 6
In Child #2, count is 6
In Child #3, count is 6
  .....In Child #1, count is 7
In Child #2, count is 7
In Child #3, count is 7
  .....In Child #1, count is 8
In Child #2, count is 8
In Child #3, count is 8
  .....In Child #1, count is 9
Child #1 terminating.
In Child #2, count is 9
Child #2 terminating.
In Child #3, count is 9
Child #3 terminating.
Main thread ending.

As you can see, once started, all three child threads share the CPU. Notice that the threads are started in the order in which they are created. However, this may not always be the case. Java is free to schedule the execution of threads in its own way. Of course, because of differences in timing or environment, the precise output from the program may differ, so don’t be surprised if you see slightly different results when you try the program.
Determining When a Thread Ends

It is often useful to know when a thread has ended. In the preceding examples, we accomplished this by watching the count variable, but this is, of course, hardly a satisfactory or generalizable solution. Fortunately, Thread provides two means by which you can determine if a thread has ended. First, you can call isAlive() on the thread. Its general form is shown here:

```java
final boolean isAlive()
```

The isAlive() method returns true if the thread upon which it is called is still running. It returns false otherwise. To try isAlive(), substitute this version of MoreThreads for the one shown in the preceding program.

```java
// Use isAlive().
class MoreThreads {
    public static void main(String args[]) {
        System.out.println("Main thread starting.");

        MyThread mt1 = new MyThread("Child #1");
        MyThread mt2 = new MyThread("Child #2");
        MyThread mt3 = new MyThread("Child #3");

        do {
            System.out.print(".");
            try {
                Thread.sleep(100);
            } catch(InterruptedException exc) {
                System.out.println("Main thread interrupted.");
            }
        } while (mt1.thrd.isAlive() ||
            mt2.thrd.isAlive() ||
            mt3.thrd.isAlive());

        System.out.println("Main thread ending.");
    }
}
```

This version produces the same output as before. The only difference is that it uses isAlive() to wait for the child threads to terminate.

Another way to wait for a thread to finish is the call join(), shown here:

```java
final void join() throws InterruptedException
```
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 `join()` allow you to specify a maximum amount of time that you want to wait for the specified thread to terminate.

Here is a program that uses `join()` to ensure that the main thread is the last to stop.

```java
// Use join().

class MyThread implements Runnable {
    int count;
    Thread thrd;

    // Construct a new thread.
    MyThread(String name) {
        thrd = new Thread(this, name);
        count = 0;
        thrd.start(); // start the thread
    }

    // Begin execution of new thread.
    public void run() {
        System.out.println(thrd.getName() + " starting.");
        try {
            do {
                Thread.sleep(500);
                System.out.println("In " + thrd.getName() + ", count is " + count);
                count++;
            } while(count < 10);
        } catch(InterruptedException exc) {
            System.out.println(thrd.getName() + " interrupted.");
        }
        System.out.println(thrd.getName() + " terminating.");
    }
}

class JoinThreads {
    public static void main(String args[]) {
        System.out.println("Main thread starting.");

        MyThread mt1 = new MyThread("Child #1");
        MyThread mt2 = new MyThread("Child #2");
        MyThread mt3 = new MyThread("Child #3");
    }
}
try {
    mt1.thrd.join();  // Wait until the specified thread ends.
    System.out.println("Child #1 joined.");
    mt2.thrd.join();
    System.out.println("Child #2 joined.");
    mt3.thrd.join();
    System.out.println("Child #3 joined.");
} 
  catch(InterruptedException exc) {
      System.out.println("Main thread interrupted.");
  }

System.out.println("Main thread ending.");

Sample output from this program is shown here. Remember that when you try the program, your precise output may vary slightly.

Main thread starting.
Child #1 starting.
Child #2 starting.
Child #3 starting.
In Child #2, count is 0
In Child #1, count is 0
In Child #3, count is 0
In Child #2, count is 1
In Child #3, count is 1
In Child #1, count is 1
In Child #2, count is 2
In Child #1, count is 2
In Child #3, count is 2
In Child #2, count is 3
In Child #3, count is 3
In Child #1, count is 3
In Child #3, count is 4
In Child #2, count is 4
In Child #1, count is 4
In Child #3, count is 5
In Child #1, count is 5
In Child #2, count is 5
In Child #3, count is 6
In Child #2, count is 6
In Child #1, count is 6
In Child #3, count is 7
In Child #1, count is 7
In Child #2, count is 7
In Child #3, count is 8
In Child #2, count is 8
In Child #1, count is 8
In Child #3, count is 9
Child #3 terminating.
In Child #2, count is 9
Child #2 terminating.
In Child #1, count is 9
Child #1 terminating.
Child #1 joined.
Child #2 joined.
Child #3 joined.
Main thread ending.

As you can see, after the calls to `join()` return, the threads have stopped executing.

**Progress Check**

1. What are the two ways in which you can determine whether a thread has finished?

2. Explain `join()`.

**CRITICAL SKILL**

11.6 Thread Priorities

Each thread has associated with it a priority setting. A thread’s priority determines, in part, how much CPU time a thread receives. In general, low-priority threads receive little. High-priority threads receive a lot. As you might expect, how much CPU time a thread receives has profound impact on its execution characteristics and its interaction with other threads currently executing in the system.

It is important to understand that factors other than a thread’s priority also affect how much CPU time a thread receives. For example, if a high-priority thread is waiting on some resource, perhaps for keyboard input, then it will be blocked, and a lower priority thread will run. However, when that high-priority thread gains access to the resource, it can preempt the low-priority thread and resume execution. Another factor that affects the scheduling of threads:

1. To determine whether a thread has ended, you can call `isAlive()` or use `join()` to wait for the thread to join the calling thread.

2. The `join()` method suspends execution of the calling thread until the thread on which `join()` is called, ends.
is the way the operating system implements multitasking. (See “Ask the Expert,” at the end of
this section.) Thus, just because you give one thread a high priority and another a low priority
does not necessarily mean that one thread will run faster or more often than the other. It’s just
that the high-priority thread has greater potential access to the CPU.

When a child thread is started, its priority setting is equal to that of its parent thread. You
can change a thread’s priority by calling setPriority( ), 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 final variables within Thread.

You can obtain the current priority setting by calling the getPriority( ) method of Thread,
shown here:

final int getPriority( )

The following example demonstrates two threads at different priorities. The threads are
created as instances of Priority. The run() method contains a loop that counts the number of
iterations. The loop stops when either the count reaches 10,000,000 or the static variable stop
is true. Initially, stop is set to false, but the first thread to finish counting sets stop to true.
This causes the second thread to terminate with its next time slice. Each time through the loop
the string in currentName is checked against the name of the executing thread. If they don’t
match, it means that a task-switch occurred. Each time a task-switch happens, the name of the
new thread is displayed, and currentName is given the name of the new thread. This allows
you to watch how often each thread has access to the CPU. After both threads stop, the number
of iterations for each loop is displayed.

    // Demonstrate thread priorities.

    class Priority implements Runnable {
        int count;
        Thread thrd;

        static boolean stop = false;
        static String currentName;

        /* Construct a new thread. Notice that this
           constructor does not actually start the
           threads running. */
Priority(String name) {
    thrd = new Thread(this, name);
    count = 0;
    currentName = name;
}

// Begin execution of new thread.
public void run() {
    System.out.println(thrd.getName() + " starting.");
    do {
        count++;
        if (currentName.compareTo(thrd.getName()) != 0) {
            currentName = thrd.getName();
            System.out.println("In " + currentName);
        }
    } while (stop == false && count < 10000000);
    stop = true;
    System.out.println("\n" + thrd.getName() + " terminating.");
}
}

class PriorityDemo {
    public static void main(String args[]) {
        Priority mt1 = new Priority("High Priority");
        Priority mt2 = new Priority("Low Priority");

        // set the priorities
        mt1.thrd.setPriority(Thread.NORM_PRIORITY+2);  // Give mt1 a higher priority than mt2.
        mt2.thrd.setPriority(Thread.NORM_PRIORITY-2);

        // start the threads
        mt1.thrd.start();
        mt2.thrd.start();

        try {
            mt1.thrd.join();
            mt2.thrd.join();
        } catch(InterruptedException exc) {
            System.out.println("Main thread interrupted.");
        }
    }
}
Here is the output produced when the program was run on a 1 GHz Pentium-based computer under Windows 2000.

High Priority starting.
In High Priority
Low Priority starting.
In Low Priority
In High Priority

High Priority terminating.

Low Priority terminating.

High priority thread counted to 10000000
Low priority thread counted to 8183

In this run, the high-priority thread got a vast majority of the CPU time. Of course, the exact output produced by this program will depend upon the speed of your CPU, the operating system you are using, and the number of other tasks running in the system.

Ask the Expert

Q: Does the operating system’s implementation of multitasking affect how much CPU time a thread receives?

A: Aside from a thread’s priority setting, the most important factor affecting thread execution is the way the operating system implements multitasking and scheduling. Some operating systems use preemptive multitasking in which each thread receives a time slice, at least occasionally. Other systems use nonpreemptive scheduling in which one thread must yield execution before another thread will execute. In nonpreemptive systems, it is easy for one thread to dominate, preventing others from running.
Synchronization

When using multiple threads, it is sometimes necessary to coordinate the activities of two or more. The process by which this is achieved is called synchronization. The most common reason for synchronization is when two or more threads need access to a shared resource that can be used by only one thread at a time. For example, when one thread is writing to a file, a second thread must be prevented from doing so at the same time. Another reason for synchronization is when one thread is waiting for an event that is caused by another thread. In this case, there must be some means by which the first thread is held in a suspended state until the event has occurred. Then, the waiting thread must resume execution.

Key to synchronization in Java is the concept of the monitor, which controls access to an object. A monitor works by implementing the concept of a lock. When an object is locked by one thread, no other thread can gain access to the object. When the thread exits, the object is unlocked and is available for use by another thread.

All objects in Java have a monitor. This feature is built into the Java language, itself. Thus, all objects can be synchronized. Synchronization is supported by the keyword synchronized and a few well-defined methods that all objects have. Since synchronization was designed into Java from the start, it is much easier to use than you might first expect. In fact, for many programs, the synchronization of objects is almost transparent.

There are two ways that you can synchronize your code. Both involve the use of the synchronized keyword, and both are examined here.

Using Synchronized Methods

You can synchronize access to a method by modifying it with the synchronized keyword. When that method is called, the calling thread enters the object’s monitor, which then locks the object. While locked, no other thread can enter the method, or enter any other synchronized method defined by the object. When the thread returns from the method, the monitor unlocks the object, allowing it to be used by the next thread. Thus, synchronization is achieved with virtually no programming effort on your part.

The following program demonstrates synchronization by controlling access to a method called sumArray(), which sums the elements of an integer array.

```java
// Use synchronize to control access.

class SumArray {
    private int sum;

    synchronized int sumArray(int nums[]) {
        // sumArray() is synchronized.
    }
```
sum = 0; // reset sum

for(int i=0; i<nums.length; i++) {
    sum += nums[i];
    System.out.println("Running total for " +
        Thread.currentThread().getName() +
        " is " + sum);
    try {
        Thread.sleep(10); // allow task-switch
    } catch(InterruptedException exc) {
        System.out.println("Main thread interrupted.");
    }
}
return sum;

class MyThread implements Runnable {
    Thread thrd;
    static SumArray sa = new SumArray();
    int a[];
    int answer;

    // Construct a new thread.
    MyThread(String name, int nums[]) {
        thrd = new Thread(this, name);
        a = nums;
        thrd.start(); // start the thread
    }

    // Begin execution of new thread.
    public void run() {
        int sum;

        System.out.println(thrd.getName() + " starting.");

        answer = sa.sumArray(a);
        System.out.println("Sum for " + thrd.getName() +
            " is " + answer);

        System.out.println(thrd.getName() + " terminating.");
    }
}

class Sync {
public static void main(String args[]) {
    int a[] = {1, 2, 3, 4, 5};

    MyThread mt1 = new MyThread("Child #1", a);
    MyThread mt2 = new MyThread("Child #2", a);
}

The output from the program is shown here.

Child #1 starting.
Running total for Child #1 is 1
Child #2 starting.
Running total for Child #1 is 3
Running total for Child #1 is 6
Running total for Child #1 is 10
Running total for Child #1 is 15
Sum for Child #1 is 15
Child #1 terminating.
Running total for Child #2 is 1
Running total for Child #2 is 3
Running total for Child #2 is 6
Running total for Child #2 is 10
Running total for Child #2 is 15
Sum for Child #2 is 15
Child #2 terminating.

Let’s examine this program in detail. The program creates three classes. The first is
SumArray. It contains the method sumArray(), which sums an integer array. The second class is
MyThread, which uses an object of type SumArray to obtain the sum of an integer array. Finally, the class Sync creates two threads and has them compute the sum of an integer array.

Inside sumArray(), sleep() is called to purposely allow a task switch to occur, if one can—but it can’t. Because sumArray() is synchronized, it can be used by only one thread at a time. Thus, when the second child thread begins execution, it does not enter sumArray() until after the first child thread is done with it. This ensures that the correct result is produced.

To fully understand the effects of synchronized, try removing it from the declaration of
sumArray(). After doing this, sumArray() is no longer synchronized, and any number of
threads may use it concurrently. The problem with this is that the running total is stored in
sum, which will be changed by each thread that calls sumArray(). Thus, when two threads
call sumArray() at the same time, incorrect results are produced because sum reflects the
summation of both threads, mixed together. For example, here is sample output from the
program after synchronized has been removed from sumArray()’s declaration. (The precise
output output may differ on your computer.)
Child #1 starting.
Running total for Child #1 is 1
Child #2 starting.
Running total for Child #2 is 1
Running total for Child #1 is 3
Running total for Child #2 is 5
Running total for Child #2 is 8
Running total for Child #1 is 11
Running total for Child #2 is 15
Running total for Child #1 is 19
Running total for Child #2 is 24
Sum for Child #2 is 24
Child #2 terminating.
Running total for Child #1 is 29
Sum for Child #1 is 29
Child #1 terminating.

As the output shows, both child threads are using `sumArray()` concurrently, and the value of `sum` is corrupted.

Before moving on, let’s review the key points of a synchronized method:

- A synchronized method is created by preceding its declaration with `synchronized`.
- For any given object, once a synchronized method has been called, the object is locked and no synchronized methods on the same object can be used by another thread of execution.
- Other threads trying to call an in-use synchronized object will enter a wait state until the object is unlocked.
- When a thread leaves the synchronized method, the object is unlocked.

**CRITICAL SKILL 11.9 The synchronized Statement**

Although creating `synchronized` methods within classes that you create is an easy and effective means of achieving synchronization, it will not work in all cases. For example, you might want to synchronize access to some method that is not modified by `synchronized`. This can occur because you want to use a class that was not created by you but by a third party, and you do not have access to the source code. Thus, it is not possible for you to 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 a synchronized block:

```java
synchronized(object) {
    // statements to be synchronized
}
```

Here, `object` is a reference to the object being synchronized. A synchronized block ensures that a call to a method that is a member of `object` will take place only after the object’s monitor has been entered by the calling thread.

For example, another way to synchronize calls to `sumArray()` is to call it from within a synchronized block, as shown in this version of the program.

```java
// Use a synchronized block to control access to SumArray.
class SumArray {
    private int sum;

    int sumArray(int nums[]) {
        sum = 0; // reset sum
        for(int i=0; i<nums.length; i++) {
            sum += nums[i];
            System.out.println("Running total for " +
                Thread.currentThread().getName() +
                " is " + sum);
            try {
                Thread.sleep(10); // allow task-switch
            }
            catch(InterruptedException exc) {
                System.out.println("Main thread interrupted.");
            }
        }
        return sum;
    }
}
```

```java
class MyThread implements Runnable {
    Thread thrd;
    static SumArray sa = new SumArray();
    int a[];
    int answer;
    ```
// Construct a new thread.
MyThread(String name, int nums[]) {
    thrd = new Thread(this, name);
    a = nums;
    thrd.start(); // start the thread
}

// Begin execution of new thread.
public void run() {
    int sum;

    System.out.println(thrd.getName() + " starting.");

    // synchronize calls to sumArray()
    synchronized(sa) {
        answer = sa.sumArray(a);
    }
    System.out.println("Sum for " + thrd.getName() + 
              " is " + answer);

    System.out.println(thrd.getName() + " terminating.");
}

class Sync {
    public static void main(String args[]) {
        int a[] = {1, 2, 3, 4, 5};

        MyThread mt1 = new MyThread("Child #1", a);
        MyThread mt2 = new MyThread("Child #2", a);

        try {
            mt1.thrd.join();
            mt2.thrd.join();
        } catch(InterruptedException exc) {
            System.out.println("Main thread interrupted.");
        }
    }
}

This version produces the same, correct output as the one shown earlier that uses a synchronized method.
Progress Check

1. How do you set a thread’s priority?
2. How do you restrict access to an object to one thread at a time?
3. The **synchronized** keyword can be used to modify a method or to create a _________ block.

**Critical Skill**

11.10 Thread Communication Using `notify()`, `wait()`, and `notifyAll()`

Consider the following situation. A thread called T is executing inside a synchronized method and needs access to a resource called R that is temporarily unavailable. What should T do? If T enters some form of polling loop that waits for R, T ties up the object, preventing other threads’ access to it. This is a less than optimal solution because it partially defeats the advantages of programming for a multithreaded environment. A better solution is to have T temporarily relinquish control of the object, allowing another thread to run. When R becomes available, T can be notified and resume execution. Such an approach relies upon some form of interthread communication in which one thread can notify another that it is blocked, and be notified that it can resume execution.

Java supports interthread communication with the `wait()`, `notify()`, and `notifyAll()` methods.

The `wait()`, `notify()`, and `notifyAll()` methods are part of all objects because they are implemented by the `Object` class. These methods can only be called from within a **synchronized** method. Here is how they are used. When a thread is temporarily blocked from running, it calls `wait()`. This causes the thread to go to sleep and the monitor for that object to be released, allowing another thread to use the object. At a later point, the sleeping thread is awakened when some other thread enters the same monitor and calls `notify()`, or `notifyAll()`. A call to `notify()` resumes one thread. A call to `notifyAll()` resumes all threads, with the highest priority thread gaining access to the object.

Following are the various forms of `wait()` defined by `Object`.

1. To set a thread’s priority, call `setPriority()`.
2. To restrict access to an object to one thread at a time, use the **synchronized** keyword.
3. `synchronized`
final void wait() throws InterruptedException
final void wait(long millis) throws InterruptedException
final void wait(long millis, int nanos) throws InterruptedException

The first form waits until notified. The second form waits until notified or until the specified period of milliseconds has expired. The third form allows you to specify the wait period in terms of nanoseconds.

Here are the general forms for notify() and notifyAll().

final void notify()
final void notifyAll()

An Example That Uses wait() and notify()

To understand the need for and the application of wait() and notify(), we will create a program that simulates the ticking of a clock by displaying the words “tick” and “tock” on the screen. To accomplish this, we will create a class called TickTock that contains two methods: tick() and tock(). The tick() method displays the word “Tick”, and tock() displays “Tock”. To run the clock, two threads are created, one that calls tick() and one that calls tock(). The goal is to make the two threads execute in a way that the output from the program displays a consistent “Tick Tock”—that is, a repeated pattern of one tick followed by one tock.

// Use wait() and notify() to create a ticking clock.
class TickTock {
  synchronized void tick(boolean running) {
    if(!running) { // stop the clock
      notify(); // notify any waiting threads
      return;
    }

    System.out.print("Tick ");
    notify(); // let tock() run
    try {
      wait(); // wait for tock() to complete
    }
    catch(InterruptedException exc) {
      System.out.println("Thread interrupted.");
    }
  }

  synchronized void tock(boolean running) {
    tick() waits for tock().
    // Tock
  }
}
if(!running) { // stop the clock
    notify(); // notify any waiting threads
    return;
}

System.out.println("Tock");
notify(); // let tick() run
try {
    wait(); // wait for tick to complete
}
catch(InterruptedException exc) {
    System.out.println("Thread interrupted.");
}
}

class MyThread implements Runnable {
    Thread thrd;
    TickTock ttOb;

    // Construct a new thread.
    MyThread(String name, TickTock tt) {
        thrd = new Thread(this, name);
        ttOb = tt;
        thrd.start(); // start the thread
    }

    // Begin execution of new thread.
    public void run() {

        if(thrd.getName().compareTo("Tick") == 0) {
            for(int i=0; i<5; i++) ttOb.tick(true);
            ttOb.tick(false);
        }
        else {
            for(int i=0; i<5; i++) ttOb.tock(true);
            ttOb.tock(false);
        }
    }
}

class ThreadCom {
    public static void main(String args[]) {
        TickTock tt = new TickTock();
        MyThread mt1 = new MyThread("Tick", tt);
        MyThread mt2 = new MyThread("Tock", tt);
        Call tick() and tock() through two different threads.
        Call tick() and tock() through two different threads.
        And, tock() waits for tick().
        And, tock() waits for tick().
        And, tock() waits for tick().
try {
    mt1.thrd.join();
    mt2.thrd.join();
} catch(InterruptedException exc) {
    System.out.println("Main thread interrupted.");
}

Here is the output produced by the program:

Tick Tock
Tick Tock
Tick Tock
Tick Tock
Tick Tock

Let’s take a close look at this program. In main(), a TickTock object called tt is created, and this object is used to start two threads of execution. Inside the run() method of MyThread, if the name of the thread is “Tick”, then calls to tick() are made. If the name of the thread is “Tock”, then the tock() method is called. Five calls that pass true as an argument are made to each method. The clock runs as long as true is passed. A final call that passes false to each method stops the clock.

The most important part of the program is found in the tick() and tock() methods. We will begin with the tick() method, which, for convenience, is shown here.

synchronized void tick(boolean running) {
    if(!running) { // stop the clock
        notify(); // notify any waiting threads
        return;
    }

    System.out.print("Tick ");
    notify(); // let tock() run
    try {
        wait(); // wait for tock() to complete
    }
    catch(InterruptedException exc) {
        System.out.println("Thread interrupted.");
    }
}

First, notice that tick() is modified by synchronized. Remember, wait() and notify() apply only to synchronized methods. The method begins by checking the value of the running
parameter. This parameter is used to provide a clean shutdown of the clock. If it is \texttt{false}, then the clock has been stopped. If this is the case, a call to \texttt{notify()} is made to enable any waiting thread to run. We will return to this point in a moment. Assuming that the clock is running when \texttt{tick()} executes, the word “Tick” is displayed, then a call to \texttt{notify()} takes place, followed by a call to \texttt{wait()}. The call to \texttt{notify()} allows a thread waiting on the same object to run. The call to \texttt{wait()} causes \texttt{tick()} to suspend until another thread calls \texttt{notify()}. Thus, when \texttt{tick()} is called, it displays one “Tick”, lets another thread run, and then suspends.

The \texttt{tock()} method is an exact copy of \texttt{tick()} except that it displays “Tock”. Thus, when entered, it displays “Tock”, calls \texttt{notify()}, and then waits. When viewed as a pair, a call to \texttt{tick()} can only be followed by a call to \texttt{tock()}, which can only be followed by a call to \texttt{tick()}, and so on. Therefore, the two methods are mutually synchronized.

The reason for the call to \texttt{notify()} when the clock is stopped is to allow a final call to \texttt{wait()} to succeed. Remember, both \texttt{tick()} and \texttt{tock()} execute a call to \texttt{wait()} after displaying their message. The problem is that when the clock is stopped, one of the methods will still be waiting. Thus, a final call to \texttt{notify()} is required in order for the waiting method to run. As an experiment, try removing this call to \texttt{notify()} and watch what happens. As you will see, the program will “hang,” and you will need to press CONTROL-C to exit. The reason for this is that when the final call to \texttt{tock()} calls \texttt{wait()}, there is no corresponding call to \texttt{notify()} that lets \texttt{tock()} conclude. Thus, \texttt{tock()} just sits there, waiting forever.

Before moving on, if you have any doubt that the calls to \texttt{wait()} and \texttt{notify()} are actually needed to make the “clock” run right, substitute this version of \texttt{TickTock} into the preceding program. It has all calls to \texttt{wait()} and \texttt{notify()} removed.

```java
// No calls to wait() or notify().
class TickTock {
    synchronized void tick(boolean running) {
        if(!running) { // stop the clock
            return;
        }
        System.out.print("Tick ");
    }

    synchronized void tock(boolean running) {
        if(!running) { // stop the clock
            return;
        }
        System.out.println("Tock");
    }
}
```
After the substitution, the output produced by the program will look like this:

Tick Tick Tick Tick Tick Tock
Tock
Tock
Tock
Tock
Tock

Clearly, the `tick()` and `tock()` methods are no longer synchronized!

---

**Progress Check**

1. What methods support interthread communication?
2. Do all objects support interthread communication?
3. What happens when `wait()` is called?

---

**Ask the Expert**

**Q:** I have heard the term *deadlock* applied to misbehaving multithreaded programs. What is it, and how can I avoid it?

**A:** Deadlock is, as the name implies, a situation in which one thread is waiting for another thread to do something, but that other thread is waiting on the first. Thus, both threads are suspended, waiting on each other, and neither executes. This situation is analogous to two overly polite people, both insisting that the other step through a door first!

Avoiding deadlock seems easy, but it’s not. For example, deadlock can occur in roundabout ways. The cause of the deadlock often is not readily understood just by looking at the source code to the program because multiply-executing threads can interact in complex ways at run time. To avoid deadlock, careful programming and thorough testing is required. Remember, if a multithreaded program occasionally “hangs,” deadlock is the likely cause.

---

1. The interthread communication methods are `wait()`, `notify()`, and `notifyAll()`.
2. Yes, all objects support interthread communication because this support is part of `Object`.
3. When `wait()` is called, the calling thread relinquishes control of the object and suspends until it receives a notification.
Suspending, Resuming, and Stopping Threads

It is sometimes useful to suspend execution of a thread. For example, a separate thread can be used to display the time of day. If the user does not desire a clock, then its thread can be suspended. Whatever the case, it is a simple matter to suspend a thread. Once suspended, it is also a simple matter to restart the thread.

The mechanisms to suspend, stop, and resume threads differ between Java 2 and earlier versions. 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. They have the following forms:

```java
final void resume()
final void suspend()
final void stop()
```

While 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. 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 was also deprecated by Java 2. This was done because this method too can sometimes cause serious system failures.

Since you cannot now use the `suspend()`, `resume()`, or `stop()` methods to control a thread, you might at first be thinking that there is no way 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 if that thread should suspend, resume, or stop its own execution. Typically, this is accomplished by establishing two flag variables: one for suspend and resume, and one for stop. For suspend and resume, as long as the 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. For the stop flag, if it is set to “stop,” the thread must terminate.

The following example shows one way to implement your own versions of `suspend()`, `resume()`, and `stop()`.
class MyThread implements Runnable {
    Thread thrd;
    volatile boolean suspended; // Suspends thread when true.
    volatile boolean stopped;  // Stops thread when true.

    MyThread(String name) {
        thrd = new Thread(this, name);
        suspended = false;
        stopped = false;
        thrd.start();
    }

    // This is the entry point for thread.
    public void run() {
        System.out.println(thrd.getName() + " starting.");
        try {
            for (int i = 1; i < 1000; i++) {
                System.out.print(i + " ");
                if (i%10==0) {
                    System.out.println();
                    Thread.sleep(250);
                }
            }
            // Use synchronized block to check suspended and stopped.
            synchronized(this) {
                while(suspended) {
                    wait();
                }
                if(stopped) break;
            }
        } catch (InterruptedException exc) {
            System.out.println(thrd.getName() + " interrupted.");
        }
        System.out.println(thrd.getName() + " exiting.");
    }

    // Stop the thread.
    synchronized void mystop() {
        stopped = true;

        // The following lets a suspended thread be stopped.
        suspended = false;
        notify();
    }
}
// Suspend the thread.
synchronized void mysuspend() {
    suspended = true;
}

// Resume the thread.
synchronized void myresume() {
    suspended = false;
    notify();
}

class Suspend {
    public static void main(String args[]) {
        MyThread ob1 = new MyThread("My Thread");

        try {
            Thread.sleep(1000); // let ob1 thread start executing

            ob1.mysuspend();
            System.out.println("Suspending thread.");
            Thread.sleep(1000);

            ob1.myresume();
            System.out.println("Resuming thread.");
            Thread.sleep(1000);

            ob1.mysuspend();
            System.out.println("Suspending thread.");
            Thread.sleep(1000);

            ob1.myresume();
            System.out.println("Resuming thread.");
            Thread.sleep(1000);

            ob1.mysuspend();
            System.out.println("Stopping thread.");
            ob1.mystop();
        } catch (InterruptedException e) {
            System.out.println("Main thread Interrupted");
        }

        // wait for thread to finish
try {
    ob1.thrd.join();
} 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 differ slightly.)

My Thread starting.
1 2 3 4 5 6 7 8 9 10
11 12 13 14 15 16 17 18 19 20
21 22 23 24 25 26 27 28 29 30
31 32 33 34 35 36 37 38 39 40
Suspending thread.
Resuming thread.
41 42 43 44 45 46 47 48 49 50
51 52 53 54 55 56 57 58 59 60
61 62 63 64 65 66 67 68 69 70
71 72 73 74 75 76 77 78 79 80
Suspending thread.
Resuming thread.
81 82 83 84 85 86 87 88 89 90
91 92 93 94 95 96 97 98 99 100
101 102 103 104 105 106 107 108 109 110
111 112 113 114 115 116 117 118 119 120
Stopping thread.
My Thread exiting.
Main thread exiting.

Here is how the program works. The thread class MyThread defines two Boolean variables, suspended and stopped, which govern the suspension and termination of a thread. Both are initialized to false by the constructor. The run() method contains a synchronized statement block that checks suspended. If that variable is true, the wait() method is invoked to suspend the execution of the thread. To suspend execution of the thread, call mysuspend(), which sets suspended to true. To resume execution, call myresume(), which sets suspended to false and invokes notify() to restart the thread.

To stop the thread, call mystop(), which sets stopped to true. In addition, mystop() sets suspended to false and then calls notify(). These steps are necessary to stop a suspended thread.
One other note about the preceding program. Notice that suspended and stopped are preceded by the keyword volatile. The volatile modifier is another of Java’s keywords, and is discussed in Module 12. Briefly, it tells the compiler that a variable can be changed unexpectedly by other parts of your program, such as another thread.

---

**Ask the Expert**

**Q:** Multithreading seems like a great way to improve the efficiency of my programs. Can you give me any tips on effectively using it?

**A:** The key to effectively utilizing multithreading is to think concurrently rather than serially. For example, when you have two subsystems within a program that are fully independent of each other, consider making them into individual threads. 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, overhead is associated with context switching. If you create too many threads, more CPU time will be spent changing contexts than in executing your program!

---

Project 11-2 Using the Main Thread

All Java programs have at least one thread of execution, called the main thread, which is given to the program automatically when it begins running. So far, we have been taking the main thread for granted. In this project, you will see that the main thread can be handled just like all other threads.

**Step by Step**

1. Create a file called **UseMain.java**.

2. To access the main thread, you must obtain a **Thread** object that refers to it. You do this by calling the **currentThread()** method, which is a **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. Therefore, if you call **currentThread()** while execution is inside the main thread, you will obtain a reference to the main thread. Once you have this reference, you can control the main thread just like any other thread.
3. Enter the following program into the file. It obtains a reference to the main thread, and then gets and sets the main thread’s name and priority.

    /*
     * Project 11-2
     *
     * Controlling the main thread.
     */
    
    class UseMain {
        public static void main(String args[]) {
            Thread thrd;
            // Get the main thread.
            thrd = Thread.currentThread();
            // Display main thread's name.
            System.out.println("Main thread is called: "+
                    thrd.getName());
            // Display main thread's priority.
            System.out.println("Priority: " +
                    thrd.getPriority());

            System.out.println();

            // Set the name and priority.
            System.out.println("Setting name and priority.\n");
            thrd.setName("Thread #1");
            thrd.setPriority(Thread.NORM_PRIORITY+3);
            System.out.println("Main thread is now called: " +
                    thrd.getName());
            System.out.println("Priority is now: " +
                    thrd.getPriority());
        }
    }

4. The output from the program is shown here.

    Main thread is called: main
    Priority: 5

(continued)
Setting name and priority.

Main thread is now called: Thread #1
Priority is now: 8

5. You need to be careful about what operations you perform on the main thread. For example, if you add the following code to the end of main(), the program will never terminate because it will be waiting for the main thread to end!

   try {
       thrd.join();
   } catch(InterruptedException exc) {
       System.out.println("Interrupted");
   }

Module 11 Mastery Check

1. Why does Java’s multithreading capability enable you to write more efficient programs?

2. Multithreading is supported by the ________ class and the ________ interface.

3. When creating a runnable object, why might you want to extend Thread rather than implement Runnable?

4. Show how to use join() to wait for a thread object called MyThrd to end.

5. Show how to set a thread called MyThrd to three levels above normal priority.

6. What is the effect of adding the synchronized keyword to a method?

7. The wait() and notify() methods are used to perform _____________________.

8. Change the TickTock class so that it actually keeps time. That is, have each tick take one half second, and each tock take one half second. Thus, each tick-tock will take one second. (Don’t worry about the time it takes to switch tasks, etc.)

9. Why can’t you use suspend(), resume(), and stop() for new programs?

10. What method defined by Thread obtains the name of a thread?

11. What does isAlive() return?

12. On your own, try adding synchronization to the Queue class developed in previous modules so that it is safe for multithreaded use.
## CRITICAL SKILLS

12.1 Understand applet basics  
12.2 Know the applet architecture  
12.3 Create an applet skeleton  
12.4 Initialize and terminate applets  
12.5 Repaint applets  
12.6 Output to the status window  
12.7 Pass parameters to an applet  
12.8 Know the `Applet` class  
12.9 Understand the delegation event model  
12.10 Use the delegation event model  
12.11 Know the remaining Java keywords
Teaching the elements of the Java language is the primary goal of this book, and in this regard, we are nearly finished. The preceding 11 modules have focused on the features of Java defined by the language, such as its keywords, syntax, block structure, type conversion rules, and so on. At this point, you have enough knowledge to write sophisticated, useful Java programs. However, there is an important part of Java programming that requires more than just an understanding of the language itself: the applet. The applet is the single most important type of Java application, and no book on Java would be complete without coverage of it. Therefore, this module presents an overview of applet programming.

Applets use a unique architecture and require the use of several special programming techniques. One of these techniques is event handling. Events are the way that an applet receives input from the outside world. Since event handling is an important part of nearly all applets, it is also introduced here.

Be forewarned: The topics of applets and event handling are very large. Full and detailed coverage of them is well beyond the scope of this book. Here you will learn their fundamentals and see several examples, but we will only scratch the surface. After finishing this module, however, you will have a solid foundation upon which to begin an in-depth study of these important topics.

This module ends with a description of a few of Java’s keywords, such as instanceof and native, that have not been described elsewhere in this book. These keywords are used for more advanced programming, but they are summarized here for completeness.

### Critical Skill

#### Applet Basics

Applets differ from the type of programs shown in the preceding modules. As mentioned in Module 1, applets are small programs that are designed for transmission over the Internet and run within a browser. Because Java’s virtual machine is in charge of executing all Java programs, including applets, applets offer a secure way to dynamically download and execute programs over the Web. Before discussing any theory or details, let’s begin by examining a simple applet. It performs one function: It displays the string “Java makes applets easy.” inside a window.

```java
// A minimal applet.
import java.awt.*;
import java.applet.*;

public class SimpleApplet extends Applet {
    public void paint(Graphics g) {
        g.drawString("Java makes applets easy.", 20, 20);
    }
}
```

Notice these import statements. They are used by all applets.

This outputs to the applet’s window.
This applet begins with two `import` statements. The first imports the Abstract Window Toolkit (AWT) classes. Applets interact with the user through the AWT, not through the console-based I/O classes. The AWT contains support for a window-based, graphical interface. As you might expect, it is quite large and sophisticated. A complete discussion of it would require a book of its own. Fortunately, since we will be creating only very simple applets, we will make only limited use of the AWT. The next `import` statement imports the `applet` package. This package contains the class `Applet`. Every applet that you create must be a subclass of `Applet`.

The next line in the program declares the class `SimpleApplet`. This class must be declared as `public` because it will be accessed by outside code.

Inside `SimpleApplet`, `paint()` is declared. This method is defined by the AWT `Component` class (which is a superclass of `Applet`) and must be overridden by the applet. `paint()` is called each time the applet must redisplay its output. This can occur for several reasons. For example, the window in which the applet is running can be overwritten by another window and then uncovered. Or the applet window can be minimized and then restored. `paint()` is also called when the applet begins execution. Whatever the cause, whenever the applet must redisplay its output, `paint()` is called. The `paint()` method has one parameter of type `Graphics`. This parameter will contain the graphics context, which describes the graphics environment in which the applet is running. This context is used whenever output to the applet is required.

Inside `paint()`, there is a call to `drawString()`, which is a member of the `Graphics` class. This method outputs a string beginning at the specified X,Y location. It has the following general form:

```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 call to `drawString()` in the applet causes the message to be displayed beginning at location 20,20.

Notice that the applet does not have a `main()` method. Unlike the programs shown earlier in this book, applets do not begin execution at `main()`. In fact, most applets don’t even have a `main()` method. Instead, an applet begins execution when the name of its class is passed to a browser or other applet-enabled program.

After you have entered the source code for `SimpleApplet`, you compile in the same way that you have been compiling programs. However, running `SimpleApplet` involves a different process. There are two ways in which you can run an applet: inside a browser or with a special development tool that displays applets. The tool provided with the standard Java SDK is called `appletviewer`, and we will use it to run the applets developed in this module. Of course, you can also run them in your browser, but the `appletviewer` is much easier to use during development.

To execute an applet (in either a Web browser or the `appletviewer`), you need to write a short HTML text file that contains the appropriate APPLET tag. (You can also use the newer
OBJECT tag, but this book will use APPLET because this is the traditional approach.) Here is the HTML file that will execute SimpleApplet:

```html
<applet code="SimpleApplet" width=200 height=60>
</applet>
```

The **width** and **height** statements specify the dimensions of the display area used by the applet.

To execute SimpleApplet with an applet viewer, you will execute this HTML file. For example, if the preceding HTML file is called *StartApp.html*, then the following command line will run SimpleApplet:

```
C:\>appletviewer StartApp.html
```

Although there is nothing wrong with using a stand-alone HTML file to execute an applet, there is an easier way. Simply include a comment near the top of your applet’s source code file that contains the APPLET tag. If you use this method, the SimpleApplet source file looks like this:

```java
import java.awt.*;
import java.applet.*;
/*
<applet code="SimpleApplet" width=200 height=60>
</applet>
*/
public class SimpleApplet extends Applet {
    public void paint(Graphics g) {
        g.drawString("Java makes applets easy.", 20, 20);
    }
}
```

Now you can execute the applet by passing the name of its source file to appletviewer. For example, this command line will now display SimpleApplet.

```
C:\>appletviewer SimpleApplet.java
```

The window produced by SimpleApplet, as displayed by appletviewer, is shown in the following illustration:
When using **appletviewer**, keep in mind that it provides the window frame. Applets run in a browser will not have a visible frame.

Let’s review an applet’s key points:

- All applets are subclasses of **Applet**.
- Applets do not need a **main( )** method.
- Applets must be run under an applet viewer or a Java-compatible browser.
- User I/O is not accomplished with Java’s stream I/O classes. Instead, applets use the interface provided by the AWT.

---

**Progress Check**

1. What is an applet?
2. What method outputs to the applet’s window?
3. What package must be included when creating an applet?
4. How are applets run?

---

1. An applet is a special type of Java program that is designed for transmission over the Internet and that runs inside a browser.
2. The **paint( )** method displays output in an applet’s window.
3. The package **java.applet** must be included when creating an applet.
4. Applets are executed by a browser or by special tools, such as **appletviewer**.
Applet Organization and Essential Elements

Although the preceding applet is completely valid, such a simple applet is of little value. Before you can create useful applets, however, you need to know more about how applets are organized, what methods they use, and how they interact with the run-time system.

**CRITICAL SKILL 12.2 The Applet Architecture**

An applet is a window-based program. As such, its architecture is different from the console-based programs shown in the first part of this book. If you are familiar with Windows programming, you will be right at home writing applets. If not, then there are a few key concepts you must understand.

First, applets are event driven, and an applet resembles a set of interrupt service routines. 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 control to the system. 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, it is the user who initiates interaction with an applet—not the other way around. In a console-based program, when the program needs input, it will prompt the user and then call some input method. 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 a 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.

While the architecture of an applet is not as easy to understand as that of a console-based program, Java makes it as simple as possible. If you have written programs for Windows, you know how intimidating that environment can be. Fortunately, Java provides a much cleaner approach that is more quickly mastered.
Although SimpleApplet shown earlier is a real applet, it does not contain all of the elements required by most applets. Actually, 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—\texttt{init()}, \texttt{start()}, \texttt{stop()}, and \texttt{destroy()}—are defined by \texttt{Applet}. The fifth method, \texttt{paint()}, you have already seen and is inherited from the AWT Component class. Since default implementations for all of these methods are provided, applets do not need to override those methods they do not use. These five methods can be assembled into the skeleton shown here:

```java
// An Applet skeleton.
import java.awt.*;
import java.applet.*;
/*
<applet code="AppletSkel" width=300 height=100>
</applet>
*/

public class AppletSkel extends Applet {
    // Called first.
    public void init() {
        // initialization
    }

    // Called second, after init(). Also called whenever the applet is restarted.
    public void start() {
        // start or resume execution
    }

    // Called when the applet is stopped.
    public void stop() {
        // suspends execution
    }

    // Called when applet is terminated. This is the last method executed.
    public void destroy() {
        // perform shutdown activities
    }
```
// Called when an applet's window must be restored.
public void paint(Graphics g) {
    // redisplay contents of window
}
}

Although this skeleton does not do anything, it can be compiled and run. Thus, it can be used as a starting point for applets that you create.

**CRITICAL SKILL 12.4**

**Applet Initialization and Termination**

It is important to understand the order in which the various methods shown in the skeleton are executed. 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.

The `init()` method is the first method to be called. In `init()` your applet will initialize variables and perform any other startup activities.

The `start()` method is called after `init()`. It is also called to restart an applet after it has been stopped, such as when the user returns to a previously displayed Web page that contains an applet. Thus, `start()` might be called more than once during the life cycle of an applet.

The `paint()` method is called each time your applet's output must be redrawn and was described earlier.

When the page containing your applet is left, the `stop()` method is called. You will use `stop()` to suspend any child threads created by the applet and to perform any other activities required to put the applet in a safe, idle state. Remember, a call to `stop()` does not mean that the applet should be terminated because it might be restarted with a call to `start()` if the user returns to the page.

The `destroy()` method is called when the applet is no longer needed. It is used to perform any shutdown operations required of the applet.
Progress Check

1. What are the five methods that most applets will override?
2. What must your applet do when `start()` is called?
3. What must your applet do when `stop()` is called?

CRITICAL SKILL

Requesting Repainting

As a general rule, an applet writes to its window only when its `paint()` method is called by the run-time system. This raises an interesting question: How can the applet itself cause its window to be updated when its information changes? For example, if an applet is displaying a moving banner, what mechanism does the applet use to update the window each time this banner scrolls? Remember that one of the fundamental architectural constraints imposed on an applet is that it must quickly return control to the Java 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 run-time system. Given this constraint, it may seem that output to your applet’s window will be difficult at best. Fortunately, this is not the case. Whenever your applet needs to update the information displayed in its window, it simply calls `repaint()`.

The `repaint()` method is defined by the AWT’s `Component` class. It causes the run-time system to execute a call to your applet’s `update()` method, which, in its default implementation, calls `paint()`. Thus, for another part of your applet to output to its window, simply store the output and then call `repaint()`. This causes a call to `paint()`, which can display the stored information. For example, if part of your applet 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 simplest version of `repaint()` is shown here:

```java
void repaint()
```

This version causes the entire window to be repainted.

1. The five methods are `init()`, `start()`, `stop()`, `destroy()`, and `paint()`.
2. When `start()` is called, the applet must be started, or restarted.
3. When `stop()` is called, the applet must be paused.
Another version of `repaint()` 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 because window updates are costly in terms of time. If you only need to update a small portion of the window, it is more efficient to repaint only that region.

An example that demonstrates `repaint()` is found in Project 12-1.

**The `update()` Method**

There is another method that relates to repainting called `update()` that your applet may want to override. This method is defined by the `Component` class, and it is called when your applet has requested that a portion of its window be redrawn. The default version of `update()` erases the applet’s window using the background color, sets the foreground color, and then calls `paint()`. An alternative approach is to override the `update()` method so that it performs all necessary display activities. Then have `paint()` simply call `update()`. Thus, for some applications, the applet skeleton will override `paint()` and `update()`, as shown here:

```java
public void update(Graphics g) {
    // redisplay your window, here.
}

public void paint(Graphics g) {
    update(g);
}
```

For the examples in this book, we will not be overriding `update()`, but this might be a useful technique in your own applets.

**Ask the Expert**

**Q:** Is it possible for a method other than `paint()` or `update()` to output to an applet’s window?

**A:** Yes. To do so, you must obtain a graphics context by calling `getGraphics()` (defined by `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 `paint()` and to call `repaint()` when the contents of the window change.
A Simple Banner Applet

To demonstrate `repaint()`, a simple banner applet is presented. This applet scrolls a message, from right to left, across the applet’s window. Since the scrolling of the message is a repetitive task, it is performed by a separate thread, created by the applet when it is initialized. Banners are popular Web features, and this project shows how to use a Java applet to create one.

Step by Step

1. Create a file called `Banner.java`.

2. Begin creating the banner applet with the following lines.

   ```java
   /*
   Project 12-1
   A simple banner applet.

   This applet creates a thread that scrolls
   the message contained in `msg` right to left
   across the applet's window.
   */
   import java.awt.*;
   import java.applet.*;
   /*
   <applet code="Banner" width=300 height=50>
   </applet>
   */
   public class Banner extends Applet implements Runnable {
       String msg = "Java Rules the Web ";
       Thread t;
       boolean stopFlag;

       // Initialize t to null.
       public void init() {
           t = null;
       }
   }
   
   Notice that `Banner` extends `Applet`, as expected, but it also implements `Runnable`. This is necessary since the applet will be creating a second thread of execution that will be used to scroll the banner. The message that will be scrolled in the banner is contained in the `String` variable `msg`. A reference to the thread that runs the applet is stored in `t`. The Boolean variable `stopFlag` is used to stop the applet. Inside `init()`, the thread reference variable `t` is set to `null`. 

(continued)
3. Add the `start()` method shown next.

```java
// Start thread
public void start() {
    t = new Thread(this);
    stopFlag = false;
    t.start();
}
```

The run-time system calls `start()` to start the applet running. Inside `start()`, a new thread of execution is created and assigned to the `Thread` variable `t`. Then, `stopFlag` is set to `false`. Next, the thread is started by a call to `t.start()`. Remember that `t.start()` calls a method defined by `Thread`, which causes `run()` to begin executing. It does not cause a call to the version of `start()` defined by `Applet`. These are two separate methods.

4. Add the `run()` method, as shown here.

```java
// Entry point for the thread that runs the banner.
public void run() {
    char ch;

    // Display banner
    for( ; ; ) {
        try {
            repaint();
            Thread.sleep(250);
            ch = msg.charAt(0);
            msg = msg.substring(1, msg.length());
            msg += ch;
            if(stopFlag)
                break;
        } catch(InterruptedException exc) {}
    }
}
```

In `run()`, the characters in the string contained in `msg` are repeatedly rotated left. Between each rotation, a call to `repaint()` is made. This eventually causes the `paint()` method to be called, and the current contents of `msg` are displayed. Between each iteration, `run()` sleeps for a quarter of a second. The net effect of `run()` is that the contents of `msg` are scrolled right to left in a constantly moving display. The `stopFlag` variable is checked on each iteration. When it is `true`, the `run()` method terminates.

5. Add the code for `stop()` and `paint()` as shown here.

```java
// Pause the banner.
public void stop() {
    stopFlag = true;
}
```
t = null;
}

// Display the banner.
public void paint(Graphics g) {
    g.drawString(msg, 50, 30);
}

If a browser is displaying the applet when a new page is viewed, the stop() method is called, which sets stopFlag to true, causing run() to terminate. It also sets t to null. Thus, there is no longer a reference to the Thread object, and it can be recycled the next time the garbage collector runs. This is the mechanism used to stop the thread when its page is no longer in view. When the applet is brought back into view, start() is once again called, which starts a new thread to execute the banner.

6. The entire banner applet is shown here:

/*
   Project 12-1

   A simple banner applet.

   This applet creates a thread that scrolls the message contained in msg right to left across the applet's window.
*/
import java.awt.*;
import java.applet.*;
/*
<applet code="Banner" width=300 height=50>
</applet>
*/

public class Banner extends Applet implements Runnable {
    String msg = " Java Rules the Web ";
    Thread t;
    boolean stopFlag;

    // Initialize t to null.
    public void init() {
        t = null;
    }

    // Start thread
    public void start() {
        t = new Thread(this);

    }

    (continued)
stopFlag = false;
t.start();
}

// Entry point for the thread that runs the banner.
public void run() {
    char ch;

    // Display banner
    for( ; ; ) {
        try {
            repaint();
            Thread.sleep(250);
            ch = msg.charAt(0);
            msg = msg.substring(1, msg.length());
            msg += ch;
            if(stopFlag)
                break;
        } catch(InterruptedException exc) {} 
    }
}

// Pause the banner.
public void stop() {
    stopFlag = true;
t = null;
}

// Display the banner.
public void paint(Graphics g) {
    g.drawString(msg, 50, 30);
}
}

Sample output is shown here:
Using the Status Window

In addition to displaying information in its window, an applet can also output a message to the status window of the browser or applet viewer on which it is running. To do so, call `showStatus()`, which is defined by `Applet`, with the string that you want displayed. The general form of `showStatus()` is shown here:

```java
void showStatus(String msg)
```

Here, `msg` is the string to be displayed.

The status window is a good place to give the user feedback about what is occurring in the applet, suggest options, or possibly report some types of errors. The status window also makes an excellent debugging aid, because it gives you an easy way to output information about your applet.

The following applet demonstrates `showStatus()`:

```java
// Using the Status Window.
import java.awt.*;
import java.applet.*;
/*
<applet code="StatusWindow" width=300 height=50>
</applet>
*/

public class StatusWindow extends Applet{
   // Display msg in applet window.
   public void paint(Graphics g) {
      g.drawString("This is in the applet window.", 10, 20);
      showStatus("This is shown in the status window.");
   }
}
```

Sample output from this program is shown here:
Passing Parameters to Applets

You can pass parameters to your applet. To do so, use the PARAM attribute of the APPLET tag, specifying the parameter's name and value. To retrieve a parameter, use the `getParameter()` method, defined by `Applet`. Its general form is shown here:

```java
String getParameter(String paramName)
```

Here, `paramName` is the name of the parameter. It returns the value of the specified parameter in the form of a `String` object. Thus, for numeric and `boolean` values, you will need to convert their string representations into their internal formats. If the specified parameter cannot be found, `null` is returned. Therefore, be sure to confirm that the value returned by `getParameter()` is valid. Also, check any parameter that is converted into a numeric value, confirming that a valid conversion took place.

Here is an example that demonstrates passing parameters:

```java
// Pass a parameter to an applet.
import java.awt.*;
import java.applet.*;

/*
 <applet code="Param" width=300 height=80>
 <param name=author value="Herb Schildt">
 <param name=purpose value="Demonstrate Parameters">
 <param name=version value=2>
 </applet>
 */

public class Param extends Applet {
    String author;
    String purpose;
    int ver;

    public void start() {
        String temp;

        author = getParameter("author");
        if(author == null) author = "not found";

        purpose = getParameter("purpose");
        if(purpose == null) purpose = "not found";

        temp = getParameter("version");
        try {
```

These HTML parameters are passed to the applet.

It is important to check that the parameter exists!
if(temp != null)
    ver = Integer.parseInt(temp);
else
    ver = 0;
} catch(NumberFormatException exc) {
    ver = -1; // error code
}
}

public void paint(Graphics g) {
    g.drawString("Purpose: "+ purpose, 10, 20);
    g.drawString("By: "+ author, 10, 40);
    g.drawString("Version: "+ ver, 10, 60);
}

Sample output from this program is shown here:

1. How do you cause an applet’s `paint()` method to be called?
2. Where does `showStatus()` display a string?
3. What method is used to obtain a parameter specified in the `APPLET` tag?

1. To cause `paint()` to be called, call `repaint()`.
2. `showStatus()` displays output in an applet’s status window.
3. To obtain a parameter, call `getParameter()`.
The Applet Class

As mentioned, all applets are subclasses of the `Applet` class. `Applet` inherits the following superclasses defined by the AWT: `Component`, `Container`, and `Panel`. Thus, an applet has access to the full functionality of the AWT.

In addition to the methods described in the preceding sections, `Applet` contains several others that give you detailed control over the execution of your applet. All of the methods defined by `Applet` are shown in Table 12-1.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void destroy( )</code></td>
<td>Called by the browser just before an applet is terminated. Your applet will override this method if it needs to perform any cleanup prior to its destruction.</td>
</tr>
<tr>
<td><code>AccessibleContext getAccessibleContext( )</code></td>
<td>Returns the accessibility context for the invoking object.</td>
</tr>
<tr>
<td><code>AppletContext getAppletContext( )</code></td>
<td>Returns the context associated with the applet.</td>
</tr>
<tr>
<td><code>String getAppletInfo( )</code></td>
<td>Returns a string that describes the applet.</td>
</tr>
<tr>
<td><code>AudioClip getAudioClip(URL url)</code></td>
<td>Returns an <code>AudioClip</code> object that encapsulates the audio clip found at the location specified by <code>url</code>.</td>
</tr>
<tr>
<td><code>AudioClip getAudioClip(URL url, String clipName)</code></td>
<td>Returns an <code>AudioClip</code> object that encapsulates the audio clip found at the location specified by <code>url</code> and having the name specified by <code>clipName</code>.</td>
</tr>
<tr>
<td><code>URL getCodeBase( )</code></td>
<td>Returns the URL associated with the invoking applet.</td>
</tr>
<tr>
<td><code>URL getDocumentBase( )</code></td>
<td>Returns the URL of the HTML document that invokes the applet.</td>
</tr>
<tr>
<td><code>Image getImage(URL url)</code></td>
<td>Returns an <code>Image</code> object that encapsulates the image found at the location specified by <code>url</code>.</td>
</tr>
<tr>
<td><code>Image getImage(URL url, String imageName)</code></td>
<td>Returns an <code>Image</code> object that encapsulates the image found at the location specified by <code>url</code> and having the name specified by <code>imageName</code>.</td>
</tr>
<tr>
<td><code>Locale getLocale( )</code></td>
<td>Returns a <code>Locale</code> object that is used by various locale-sensitive classes and methods.</td>
</tr>
</tbody>
</table>

Table 12-1  The Methods Defined by `Applet`
### Table 12-1 The Methods Defined by Applet (continued)

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>String getParameter(String paramName)</td>
<td>Returns the parameter associated with paramName. <strong>null</strong> is returned if the specified parameter is not found.</td>
</tr>
<tr>
<td>String[][] getParameterInfo( )</td>
<td>Returns a <strong>String</strong> table that describes the parameters recognized by the applet. Each entry in the table must consist of three strings that contain the name of the parameter, a description of its type and/or range, and an explanation of its purpose.</td>
</tr>
<tr>
<td>void init( )</td>
<td>This method is called when an applet begins execution. It is the first method called for any applet.</td>
</tr>
<tr>
<td>boolean isActive( )</td>
<td>Returns <strong>true</strong> if the applet has been started. It returns <strong>false</strong> if the applet has been stopped.</td>
</tr>
<tr>
<td>static final AudioClip newAudioClip(URL url)</td>
<td>Returns an <strong>AudioClip</strong> object that encapsulates the audio clip found at the location specified by url. This method is similar to <strong>getAudioClip( )</strong> except that it is static and can be executed without the need for an <strong>Applet</strong> object.</td>
</tr>
<tr>
<td>void play(URL url)</td>
<td>If an audio clip is found at the location specified by url, the clip is played.</td>
</tr>
<tr>
<td>void play(URL url, String clipName)</td>
<td>If an audio clip is found at the location specified by url with the name specified by clipName, the clip is played.</td>
</tr>
<tr>
<td>void resize(Dimension dim)</td>
<td>Resizes the applet according to the dimensions specified by dim. <strong>Dimension</strong> is a class stored inside <strong>java.awt</strong>. It contains two integer fields: <strong>width</strong> and <strong>height</strong>.</td>
</tr>
<tr>
<td>void resize(int width, int height)</td>
<td>Resizes the applet according to the dimensions specified by <strong>width</strong> and <strong>height</strong>.</td>
</tr>
<tr>
<td>final void setStub(AppletStub stubObj)</td>
<td>Makes stubObj the stub for the applet. This method is used by the run-time system and is not usually called by your applet. A stub is a small piece of code that provides the linkage between your applet and the browser.</td>
</tr>
<tr>
<td>void showStatus(String str)</td>
<td>Displays str in the status window of the browser or applet viewer. If the browser does not support a status window, then no action takes place.</td>
</tr>
<tr>
<td>void start( )</td>
<td>Called by the browser when an applet should start (or resume) execution. It is automatically called after <strong>init( )</strong> when an applet first begins.</td>
</tr>
<tr>
<td>void stop( )</td>
<td>Called by the browser to suspend execution of the applet. Once stopped, an applet is restarted when the browser calls <strong>start( )</strong>.</td>
</tr>
</tbody>
</table>
Event Handling

Applets are event-driven programs. Thus, event handling is at the core of successful applet programming. Most events to which your applet will respond are generated by the user. These events are passed to your applet in a variety of ways, with the specific method depending upon the actual event. There are several types of events. The most commonly handled events are those generated by the mouse, the keyboard, and various controls, such as a push button. Events are supported by the `java.awt.event` package.

Before beginning our discussion of event handling, an important point must be made: The way events are handled by an applet changed significantly between the original version of Java (1.0) and modern versions of Java, beginning with version 1.1. The 1.0 method of event handling is still supported, but 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 it is the method described here.

Once again, it must be mentioned that it is not possible to fully discuss Java’s event handling mechanism. Event handling is a large topic with many special features and attributes, and a complete discussion is well beyond the scope of this book. However, the overview presented here will help you get started.

**CRITICAL SKILL 12.9 The Delegation Event Model**

The modern approach to handling events is based on the *delegation event model*. The delegation event model 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 received, the listener processes the event and then returns. The advantage of this design is that the 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.

**Events**

In the delegation model, an event is an object that describes a state change in a source. It can be generated as a consequence of a person interacting with the elements in a graphical user interface, such as pressing a button, entering a character via the keyboard, selecting an item in a list, and clicking the mouse.
Event Sources

An event source is an object that generates an event. A source must register listeners in order for the listener to receive notifications about a specific type of event. Each type of event has its own registration method. Here is the general form:

```java
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()` and 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.

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:

```java
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, the `Component` class 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.

The methods that receive and process events are defined in a set of interfaces found in the `java.awt.event` package. For example, the `MouseMotionListener` interface defines methods that receive notifications when the mouse is dragged or moved. Any object may receive and process one or both of these events if it provides an implementation of this interface.

Event Classes

The classes that represent events are at the core of Java’s event handling mechanism. At the root of the Java event class hierarchy is `EventObject`, which is in `java.util`. It is the superclass for all events. The class `AWTEvent`, defined within the `java.awt` package, is a subclass of
Event Object. It is the superclass (either directly or indirectly) for all AWT-based events used by the delegation event model.

The package java.awt.event defines several types of events that are generated by various user interface elements. Table 12-2 enumerates the most commonly used ones and provides a brief description of when they are generated.

Event Listener Interfaces
Event listeners receive event notifications. 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 12-3 lists commonly used listener interfaces and provides a brief description of the methods they define.

<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 or moved, clicked, pressed, or released; also generated when the mouse enters or exits a component.</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 12-2 The Main Event Classes in java.awt.event
Progress Check

1. Briefly explain the significance of `EventObject` and `AWTEvent`.

2. What is an event source? What is an event listener?

3. Listeners must be registered with a source in order to receive event notifications. True or False?

---

1. `EventObject` is a superclass of all events. `AWTEvent` is a superclass of all AWT events that are handled by the delegation event model.

2. An event source generates events. An event listener receives event notifications.

3. True.
Using the Delegation Event Model

Now that you have had an overview of the delegation event model and its various components, it is time to see it in practice. Applet programming 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 will 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.

To see how the delegation model works in practice, we will look at an example that handles one of the most commonly used event generators: the mouse.

Handling Mouse Events

To handle mouse events, you must implement the `MouseListener` and the `MouseMotionListener` interfaces. The `MouseListener` interface defines five methods. If a mouse button is clicked, `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 a mouse button 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 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 MouseEvent object passed in me describes the event. MouseEvent defines a number of methods that you can use to get information about what happened. Probably the most commonly used methods in MouseEvent are getX() and getY(). These return the X and Y coordinates of the mouse when the event occurred. Their forms are shown here:

```java
int getX()
int getY()
```

The next example will use these methods to display the current location of the mouse.

A Simple Mouse Event Applet
The following applet demonstrates handling mouse events. It displays the current coordinates of the mouse in the applet’s status window. Each time a button is pressed, the word “Down” is displayed at the location of the mouse pointer. Each time the button is released, the word “Up” is shown. If a button is clicked, the message “Mouse clicked” is displayed in the upper-left corner of the applet display area.

As the mouse enters or exits the applet window, a message is displayed in the upper-left corner of the applet display area. 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 the mouse event handlers.
import java.awt.*;
import java.awt.event.*;
import java.applet.*;
/*
 <applet code="MouseEvents" width=300 height=100>
 </applet>
 */

public class MouseEvents extends Applet
implements MouseListener, MouseMotionListener {

    String msg = "";
    int mouseX = 0, mouseY = 0; // coordinates of mouse

    public void init() {
        addMouseListener(this);
        addMouseMotionListener(this);
    }
```
// Handle mouse clicked.
public void mouseClicked(MouseEvent me) {
    mouseX = 0;
    mouseY = 10;
    msg = "Mouse clicked."
    repaint();
}

// Handle mouse entered.
public void mouseEntered(MouseEvent me) {
    mouseX = 0;
    mouseY = 10;
    msg = "Mouse entered."
    repaint();
}

// Handle mouse exited.
public void mouseExited(MouseEvent me) {
    mouseX = 0;
    mouseY = 10;
    msg = "Mouse exited."
    repaint();
}

// Handle button pressed.
public void mousePressed(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "Down"
    repaint();
}

// Handle button released.
public void mouseReleased(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "Up";
    repaint();
}

// Handle mouse dragged.
public void mouseDragged(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();

This, and the other event handlers, respond to mouse events.
msg = "*";
showStatus("Dragging mouse at " + mouseX + ", " + mouseY);
repaint();
}

// Handle mouse moved.
public void mouseMoved(MouseEvent me) {
    // show status
    showStatus("Moving mouse at " + me.getX() + ", " + me.getY());
}

// Display msg in applet window at current X,Y location.
public void paint(Graphics g) {
    g.drawString(msg, mouseX, mouseY);
}
}

Sample output from this program is shown here:

Let’s look closely at this example. The `MouseEvent` class extends `Applet` and implements both the `MouseListener` and `MouseMotionListener` interfaces. These two interfaces contain methods that receive and process the various types of mouse events. Notice that the applet is both the source and the listener for these events. This works because `Component`, which supplies the `addMouseListener()` and `addMouseMotionListener()` methods, is a superclass of `Applet`. Being both the source and the listener for events is a common situation for applets.

Inside `init()`, the applet registers itself as a listener for mouse events. This is done by using `addMouseListener()` and `addMouseMotionListener()`, which are members of `Component`. They are shown here:

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.

The applet then implements all of the methods defined by the \texttt{MouseListener} and \texttt{MouseMotionListener} interfaces. These are the event handlers for the various mouse events. Each method handles its event and then returns.

**Critical Skill 12.11**

**More Java Keywords**

Before concluding this book, a few more Java keywords need to be briefly discussed:

- \texttt{transient}
- \texttt{volatile}
- \texttt{instanceof}
- \texttt{native}
- \texttt{strictfp}
- \texttt{assert}

These keywords are used in programs more advanced than those found in this book. However, an overview of each is presented so that you will know their purpose.

**The transient and volatile Modifiers**

The \texttt{transient} and \texttt{volatile} keywords are type modifiers that handle somewhat specialized situations. When an instance variable is declared as \texttt{transient}, then its value need not persist when an object is stored. Thus, a \texttt{transient} field is one that does not affect the state of an object.

The \texttt{volatile} modifier was mentioned briefly in Module 11 but warrants a closer look. Modifying a variable with \texttt{volatile} tells the compiler that the variable can be changed unexpectedly by other parts of your program. As you saw in Module 11, one of these situations involves multithreaded programs. In a multithreaded program, sometimes two or more threads will share the same instance variable. For efficiency considerations, each thread can keep its own, private copy of such a shared variable. The real (or \texttt{master}) copy of the variable is updated at various times, such as when a \texttt{synchronized} method is entered. While this approach works fine, there may be times when it is inefficient. 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 \texttt{volatile}. Doing so tells the compiler that it must always use the master copy of a \texttt{volatile} variable (or, at least, always keep any private copies up to date).
with the master copy and vice versa). Also, accesses to the master variable must be executed in the precise order in which they are executed on any private copy.

**instanceof**

Sometimes it is useful to know the type of an object during run time. 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 only be detected at run time. Because a superclass reference can refer to subclass objects, it is not always possible to know at compile time whether or not a cast involving a superclass reference is valid. The `instanceof` keyword addresses these types of situations.

The `instanceof` operator has this general form:

```java
object instanceof type
```

Here, `object` is an instance of a class, and `type` is a class type. If `object` 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.

**strictfp**

Java 2 added a new keyword to the Java language called `strictfp`. With the creation of Java 2, the floating-point computation model was relaxed slightly to make certain floating-point computations faster for certain processors, such as the Pentium. Specifically, the new model does not require the truncation of certain intermediate values that occur during a computation. By modifying a class or a method with `strictfp`, you ensure that floating-point calculations (and thus all truncations) take place precisely as they did in earlier versions of Java. The truncation affects only the exponent of certain operations. When a class is modified by `strictfp`, all of the methods in the class are also `strictfp` automatically.

**assert**

The `assert` keyword was added to the Java language in 2002 by Java 2, version 1.4, so it is a very recent addition. It is used during program development to create an *assertion*, which is a condition that is expected to 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 actually 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:

```
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. For example,

```
assert n > 0;
```

If `n` is less than or equal to zero, then an `AssertionError` is thrown. Otherwise, no action takes place.

The second form of `assert` is shown here:

```
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.

Programs that use `assert` must be compiled using the `-source 1.4` option. For example, to compile a program called `Sample.java` that contains an assertion, use this line:

```
javac -source 1.4 Sample.java
```

To enable assertion checking at run time, you must specify the `-ea` option. For example, to enable assertions for `Sample`, execute it using this line:

```
java -ea Sample
```

Assertions are a good addition to Java because they streamline the type of error checking that is common during development. But be careful—you must not rely on an assertion to perform any action actually required by the program. The reason is that normally, released code will be run with assertions disabled and the expression in an assertion will not be evaluated.
Native Methods

Although rare, there may occasionally be times when you will want to call a subroutine that is written in a language other than Java. Typically, such a subroutine will exist as executable code for the CPU and environment in which you are working—that is, native code. For example, you may wish to call a native code subroutine in order to achieve faster execution time. Or you may want to use a specialized, third-party library, such as a statistical package. However, since 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.

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() ;
```

Once you have declared a native method, you must write the native method and follow a rather complex series of steps in order to link it with your Java code.

What Next?

Congratulations! If you have read and worked through the preceding 12 modules, then you can call yourself a Java programmer. Of course, there are still many, many things to learn about Java, its libraries, and its subsystems, but you now have a solid foundation upon which you can build your knowledge and expertise.

Here are a few of the topics that you will want to learn more about:

- The Abstract Window Toolkit (AWT), including its various user interface elements, such as push buttons, menus, lists, and scroll bars.
- Layout managers, which control how elements are displayed in an applet.
- Handling text and graphics output in a window.
- The event handling subsystem. Although introduced here, there is substantially more to it.
- Java’s networking classes.
- Java’s utility classes, especially its Collections Framework, which simplifies a number of common programming tasks.
Module 12: Applets, Events, and Miscellaneous Topics

- Swing, which is an alternative to the AWT.
- Java Beans, which supports the creation of software components in Java.
- Creating native methods.

To continue your study of Java, I recommend my book *Java 2: The Complete Reference* (McGraw-Hill/Osborne), which covers all the topics just mentioned plus many more. In it you will find complete coverage of the Java language, its libraries, subsystems, and application.

**Module 12 Mastery Check**

1. What method is called when an applet first begins running? What method is called when an applet is removed from the system?
2. Explain why an applet must use multithreading if it needs to run continually.
3. Enhance Project 12-1 so that it displays the string passed to it as a parameter. Add a second parameter that specifies the time delay (in milliseconds) between each rotation.
4. Extra challenge: Create an applet that displays the current time, updated once per second. To accomplish this, you will need to do a little research. Here is a hint to help you get started: The easiest way to obtain the current time is to use a `Calendar` object, which is part of the `java.util` package. (Remember, Sun provides online documentation for all of Java’s standard classes.) You should now be at the point where you can examine the `Calendar` class on your own and use its methods to solve this problem.
5. Briefly explain Java’s delegation event model.
6. Must an event listener register itself with a source?
7. Extra challenge: Another of Java’s display methods is `drawLine()`. It draws a line in the currently selected color between two points. It is part of the `Graphics` class. Using `drawLine()`, write a program that tracks mouse movement. If the button is pressed, have the program draw a continuous line until the mouse button is released.
8. Briefly describe the `assert` keyword.
9. Give one reason why a native method might be useful to some types of programs.
10. On your own, continue to learn about Java. A good place to start is by examining Java’s standard packages, such as `java.util`, `java.awt`, and `java.net`. These contain many exciting classes that enable you to create powerful, Internet-enabled applications.
Appendix A

Answers to Mastery Checks
Module 1: Java Fundamentals

1. What is bytecode and why is it important to Java’s use for Internet programming?

Bytecode is a highly optimized set of instructions that is executed by the Java run-time interpreter. Bytecode helps Java achieve both portability and security.

2. What are the three main principles of object-oriented programming?

Encapsulation, polymorphism, and inheritance.

3. Where do Java programs begin execution?

Java programs begin execution at main().

4. What is a variable?

A variable is a named memory location. The contents of a variable can be changed during the execution of a program.

5. Which of the following variable names is invalid?

The invalid variable is d. Variable names cannot begin with a digit.

6. How do you create a single-line comment? How do you create a multiline comment?

A single-line comment begins with // and ends at the end of the line. A multiline comment begins with /* and ends with */.

7. Show the general form of the if statement. Show the general form of the for loop.

The general form of the if:

    if(condition) statement;

The general form of the for:

    for(initialization; condition; iteration) statement;

8. How do you create a block of code?

A block of code is started with a { and ended with a }.

9. The moon’s gravity is about 17 percent that of the earth’s. Write a program that computes your effective weight on the moon.

    /*
    Compute your weight on the moon.
    
    Call this file Moon.java.
    */
class Moon {
    public static void main(String args[]) {
        double earthweight; // weight on earth
        double moonweight; // weight on moon

        earthweight = 165;
        moonweight = earthweight * 0.17;

        System.out.println(earthweight +
                " earth-pounds is equivalent to " +
                moonweight + " moon-pounds.");
    }
}

10. Adapt Project 1-2 so that it prints a conversion table of inches to meters. Display 12 feet of conversions, inch by inch. Output a blank line every 12 inches. (One meter equals approximately 39.37 inches.)

    /*
     * This program displays a conversion
     * table of inches to meters.
     *
     * Call this program InchToMeterTable.java.
     */
    class InchToMeterTable {
        public static void main(String args[]) {
            double inches, meters;
            int counter;

            counter = 0;
            for(inches = 1; inches <= 144; inches++) {
                meters = inches / 39.37; // convert to meters
                System.out.println(inches + " inches is " +
                        meters + " meters.");

                counter++;
                // every 12th line, print a blank line
                if(counter == 12) {
                    System.out.println();
                    counter = 0; // reset the line counter
                }
            }
        }
    }
11. If you make a typing mistake when entering your program, what sort of error will result?
   A syntax error.

12. Does it matter where on a line you put a statement?
   No, Java is a free-form language.

Module 2: Introducing Data Types and Operators

1. Why does Java strictly specify the range and behavior of its simple types?
   Java strictly specifies the range and behavior of its simple types to ensure portability across platforms.

2. What is Java’s character type, and how does it differ from the character type used by many other programming languages?
   Java’s character type is `char`. Java characters are Unicode rather than ASCII, which is used by most other computer languages.

3. A boolean value can have any value you like because any non-zero value is true.
   True or False?
   False. A boolean value must be either `true` or `false`.

4. Given this output,
   ```
   One
   Two
   Three
   ```
   use a single string to show the `println()` statement that produced it.
   ```
   System.out.println("One\nTwo\nThree");
   ```

5. What is wrong with this fragment?
   ```java
   for(i = 0; i < 10; i++) {
       int sum;

       sum = sum + i;
   }
   System.out.println("Sum is: " + sum);
   ```
   There are two fundamental flaws in the fragment. First, `sum` is created each time the block created by the `for` loop is entered and destroyed on exit. Thus, it will not hold its value between iterations. Attempting to use `sum` to hold a running sum of the iterations is pointless. Second, `sum` will not be known outside of the block in which it is declared. Thus, the reference to it in the `println()` statement is invalid.
6. Explain the difference between the prefix and postfix forms of the increment operator.

When the increment operator precedes its operand, Java will perform the corresponding operation prior to obtaining the operand’s value for use by the rest of the expression. If the operator follows its operand, then Java will obtain the operand’s value before incrementing.

7. Show how a short-circuit AND can be used to prevent a divide-by-zero error.

```java
if((b != 0) && (val / b) ...)
```

8. In an expression, what type are `byte` and `short` promoted to?

In an expression, `byte` and `short` are promoted to `int`.

9. In general, when is a cast needed?

A cast is needed when converting between incompatible types or when a narrowing conversion is occurring.

10. Write a program that finds all of the prime numbers between 1 and 100.

```java
// Find prime numbers between 1 and 100.
class Prime {
    public static void main(String args[]) {
        int i, j;
        boolean isprime;

        for(i=1; i < 100; i++) {
            isprime = true;

            // see if the number is evenly divisible
            for(j=2; j < i/2; j++)
                // if it is, then it's not prime
                if((i%j) == 0) isprime = false;

            if(isprime)
                System.out.println(i + " is prime.");
        }
    }
}
```

11. Does the use of redundant parentheses affect program performance?

No.

12. Does a block define a scope?

Yes.
Module 3: Program Control Statements

1. Write a program that reads characters from the keyboard until a period is received. Have the program count the number of spaces. Report the total at the end of the program.

   // Count spaces.
   class Spaces {
   public static void main(String args[])
   throws java.io.IOException {

         char ch;
         int spaces = 0;

         System.out.println("Enter a period to stop.");

         do {
             ch = (char) System.in.read();
             if(ch == ' ') spaces++;
         } while(ch != '.');

         System.out.println("Spaces: " + spaces);
   }
   }

2. Show the general form of the if-else-if ladder.

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

3. Given

   if(x < 10)
   if(y > 100) {
       if(!done) x = z;
       else y = z;
   }
   else System.out.println("error"); // what if?
to what if does the last else associate?

The last else associates with the outer if, which is the nearest if at the same level as the else.

4. Show the for statement for a loop that counts from 1000 to 0 by –2.

```java
for(int i = 1000; i >= 0; i -= 2) // ...
```

5. Is the following fragment valid?

```java
for(int i = 0; i < num; i++)
    sum += i;

count = i;
```

No; i is not known outside of the for loop in which it is declared.

6. Explain what break does. Be sure to explain both of its forms.

A break without a label causes termination of its immediately enclosing loop or switch statement. A break with a label causes control to transfer to the end of the labeled block.

7. In the following fragment, after the break statement executes, what is displayed?

```java
for(i = 0; i < 10; i++) {
    while(running) {
        if(x<y) break;
        // ...
    }
    System.out.println("after while");
}
System.out.println("After for");
```

After break executes, “after while” is displayed.

8. What does the following fragment print?

```java
for(int i = 0; i<10; i++) {
    System.out.print(i + " ");
    if((i%2) == 0) continue;
    System.out.println();
}
```

Here is the answer:

0 1
2 3
4 5
6 7
8 9
9. The iteration expression in a for loop need not always alter the loop control variable by a fixed amount. Instead, the loop control variable can change in any arbitrary way. Using this concept, write a program that uses a for loop to generate and display the progression 1, 2, 4, 8, 16, 32, and so on.

/* Use a for loop to generate the progression */

1 2 4 8 16, ...

class Progress {
    public static void main(String args[]) {
        for(int i = 1; i < 100; i += i)
            System.out.print(i + " ");
    }
}

10. The ASCII lowercase letters are separated from the uppercase letters by 32. Thus, to convert a lowercase letter to uppercase, subtract 32 from it. Use this information to write a program that reads characters from the keyboard. Have it convert all lowercase letters to uppercase, and all uppercase letters to lowercase, displaying the result. Make no changes to any other character. Have the program stop when the user presses period. At the end, have the program display the number of case changes that have taken place.

    // Change case.
    class CaseChg {
        public static void main(String args[]) throws java.io.IOException {
            char ch;
            int changes = 0;

            System.out.println("Enter period to stop.");

            do {
                ch = (char) System.in.read();
                if(ch >= 'a' & ch <= 'z') {
                    ch -= 32;
                    changes++;
                    System.out.println(ch);
                }
                else if(ch >= 'A' & ch <= 'Z') {
                    ch += 32;
                    changes++;
                    System.out.println(ch);
                }
            } while(ch != '.');
        }
    }
11. What is an infinite loop?
An infinite loop is a loop that runs indefinitely.

12. When using break with a label, must the label be on a block that contains the break?
Yes.

Module 4: Introducing Classes, Objects, and Methods

1. What is the difference between a class and an object?
A class is a logical abstraction that describes the form and behavior of an object. An object is a physical instance of the class.

2. How is a class defined?
A class is defined by using the keyword class. Inside the class statement, you specify the code and data that comprise the class.

3. What does each object have its own copy of?
Each object of a class has its own copy of the class’s instance variables.

4. Using two separate statements, show how to declare an object called counter of a class called MyCounter.
MyCounter counter;
counter = new MyCounter();

5. Show how a method called myMeth() is declared if it has a return type of double and has two int parameters called a and b.
double myMeth(int a, int b) { // ...}

6. How must a method return if it returns a value?
A method that returns a value must return via the return statement, passing back the return value in the process.

7. What name does a constructor have?
A constructor has the same name as its class.
8. What does `new` do?

The `new` operator allocates memory for an object and initializes it using the object’s constructor.

9. What is garbage collection and how does it work? What is `finalize()`?

Garbage collection is the mechanism that recycles unused objects so that their memory can be reused. An object’s `finalize()` method is called just prior to an object being recycled.

10. What is `this`?

The `this` keyword is a reference to the object on which a method is invoked. It is automatically passed to a method.

11. Can a constructor have one or more parameters?

   Yes.

12. If a method returns no value, what must its return type be?

    `void`

---

Module 5: More Data Types and Operators

1. Show two ways to declare a one-dimensional array of 12 `double`s.

```java
double x[] = new double[12];
double[] x = new double[12];
```

2. Show how to initialize a one-dimensional array of integers to the value 1 through 5.

```java
int x[] = { 1, 2, 3, 4, 5 };`
4. Change the sort in Project 5-1 so that it sorts an array of strings. Demonstrate that it works.

```java
class StrBubble {
    public static void main(String args[]) {
        String strs[] = {
            "this", "is", "a", "test",
            "of", "a", "string", "sort"
        };
        int a, b;
        String t;
        int size;
        size = strs.length; // number of elements to sort
        // display original array
        System.out.print("Original array is:");
        for(int i=0; i < size; i++)
            System.out.print(" "+strs[i]);
        System.out.println();
        // This is the bubble sort for strings.
        for(a=1; a < size; a++)
            for(b=size-1; b >= a; b--) {
                if(strs[b-1].compareTo(strs[b]) > 0) { // if out of order
                    // exchange elements
                    t = strs[b-1];
                    strs[b-1] = strs[b];
                    strs[b] = t;
                }
            }
        // display sorted array
        System.out.print("Sorted array is:");
        for(int i=0; i < size; i++)
            System.out.print(" "+strs[i]);
        System.out.println();
    }
}
```

5. What is the difference between the String methods `indexOf()` and `lastIndexOf()`?

The `indexOf()` method finds the first occurrence of the specified substring. `lastIndexOf()` finds the last occurrence.
6. Since all strings are objects of type `String`, show how you can call the `length()` and `charAt()` methods on this string literal: "I like Java".

As strange as it may look, this is a valid call to `length()`:

```java
System.out.println("I like Java").length();
```

The output displayed is 11. `charAt()` is called in a similar fashion.

7. Expanding on the `Encode` cipher class, modify it so that it uses an eight-character string as the key.

```java
// An improved XOR cipher.
class Encode {
    public static void main(String args[]) {
        String msg = "This is a test";
        String encmsg = "";
        String decmsg = "";
        String key = "abcdefgi";
        int j;

        System.out.print("Original message: ");
        System.out.println(msg);

        // encode the message
        j = 0;
        for(int i=0; i < msg.length(); i++) {
            encmsg = encmsg + (char) (msg.charAt(i) ^ key.charAt(j));
            j++;
            if(j==8) j = 0;
        }

        System.out.print("Encoded message: ");
        System.out.println(encmsg);

        // decode the message
        j = 0;
        for(int i=0; i < msg.length(); i++) {
            decmsg = decmsg + (char) (encmsg.charAt(i) ^ key.charAt(j));
            j++;
            if(j==8) j = 0;
        }

        System.out.print("Decoded message: ");
        System.out.println(decmsg);
    }
}
```
8. Can the bitwise operators be applied to the double type?

No.

9. Show how this sequence can be rewritten using the ? operator.

```java
if(x < 0) y = 10;
else y = 20;

Here is the answer:
y = x < 0 ? 10 : 20;
```

10. In the following fragment, is the & a bitwise or logical operator? Why?

```java
boolean a, b;
// ...
if(a & b) ...
```

It is a logical operator because the operands are of type boolean.

11. Is it an error to overrun the end of an array?

Yes.

Is it an error to index an array with a negative value?

Yes. All array indexes start at zero.

12. What is the unsigned right-shift operator?

```java
>>> 
```

Module 6: A Closer Look at Methods and Classes

1. Given this fragment,

```java
class X {
    private int count;
}
```

is the following fragment correct?

```java
class Y {
    public static void main(String args[]) {
        X ob = new X();
        ob.count = 10;
    }
}
```

No; a private member cannot be accessed outside of its class.

2. An access specifier must _________ a member’s declaration.

precede
3. The complement of a queue is a stack. It uses first-in, last-out accessing and is often likened to a stack of plates. The first plate put on the table is the last plate used. Create a stack class called `Stack` that can hold characters. Call the methods that access the stack `push( )` and `pop( )`. Allow the user to specify the size of the stack when it is created. Keep all other members of the `Stack` class private. (Hint: You can use the `Queue` class as a model; just change the way that the data is accessed.)

```java
// A stack class for characters.
class Stack {
    private char stck[]; // this array holds the stack
    private int tos;  // top of stack

    // Construct an empty Stack given its size.
    Stack(int size) {
        stck = new char[size]; // allocate memory for stack
        tos = 0;
    }

    // Construct a Stack from a Stack.
    Stack(Stack ob) {
        tos = ob.tos;
        stck = new char[ob.stck.length];

        // copy elements
        for(int i=0; i < tos; i++)
            stck[i] = ob.stck[i];
    }

    // Construct a stack with initial values.
    Stack(char a[]) {
        stck = new char[a.length];

        for(int i = 0; i < a.length; i++) {
            push(a[i]);
        }
    }

    // Push characters onto the stack.
    void push(char ch) {
        if(tos==stck.length) {
            System.out.println(" -- Stack is full.");
            return;
        }
    }
```
stck[tos] = ch;
tos++;
}

// Pop a character from the stack.
char pop() {
    if(tos==0) {
        System.out.println(" -- Stack is empty.");
        return (char) 0;
    }

    tos--;
    return stck[tos];
}

// Demonstrate the Stack class.
class SDemo {
public static void main(String args[]) {
    // construct 10-element empty stack
    Stack stk1 = new Stack(10);

    char name[] = {'T', 'o', 'm'};

    // construct stack from array
    Stack stk2 = new Stack(name);

    char ch;
    int i;

    // put some characters into stk1
    for(i=0; i < 10; i++)
        stk1.push((char) ('A' + i));

    // construct stack from another stack
    Stack stk3 = new Stack(stk1);

    // show the stacks.
    System.out.print("Contents of stk1: ");
    for(i=0; i < 10; i++) {
        ch = stk1.pop();
        System.out.print(ch);
    }

    System.out.println("\n");
System.out.print("Contents of stk2: ");
for(i=0; i < 3; i++) {
    ch = stk2.pop();
    System.out.print(ch);
}
System.out.println("\n");
System.out.print("Contents of stk3: ");
for(i=0; i < 10; i++) {
    ch = stk3.pop();
    System.out.print(ch);
}
}

Here is the output from the program.
Contents of stk1: JIHGFEDCBA
Contents of stk2: moT
Contents of stk3: JIHGFEDCBA

4. Given this class:

```java
class Test {
    int a;
    Test(int i) { a = i; }
}
```

write a method called `swap()` that exchanges the contents of the objects referred to by two `Test` object references.

```java
void swap(Test ob1, Test ob2) {
    int t;
    t = ob1.a;
    ob1.a = ob2.a;
    ob2.a = t;
}
```

5. Is the following fragment correct?

```java
class X {
    int meth(int a, int b) { ... }
    String meth(int a, int b) { ... }
}
```

No. Overloaded methods can have different return types, but they do not play a role in overload resolution. Overloaded methods must have different parameter lists.
6. Write a recursive method that displays the contents of a string backwards.

```java
// Display a string backwards using recursion.
class Backwards {
    String str;
    Backwards(String s) {
        str = s;
    }
    void backward(int idx) {
        if(idx != str.length()-1) backward(idx+1);
        System.out.print(str.charAt(idx));
    }
}

class BWDemo {
    public static void main(String args[]) {
        Backwards s = new Backwards("This is a test");
        s.backward(0);
    }
}
```

7. If all objects of a class need to share the same variable, how must you declare that variable?

Shared variables are declared as **static**.

8. Why might you need to use a **static** block?

A **static** block is used to perform any initializations related to the class, before any objects are created.

9. What is an inner class?

An inner class is a nonstatic nested class.

10. To make a member accessible by only other members of its class, what access specifier must be used?

    **private**

11. The name of a method plus its parameter list constitutes the method’s **signature**.

12. An **int** argument is passed to a method by using call-by-**value**.
Module 7: Inheritance

1. Does a superclass have access to the members of a subclass? Does a subclass have access to the members of a superclass?

No, a superclass has no knowledge of its subclasses. Yes, a subclass has access to all nonprivate members of its superclass.

2. Create a subclass of TwoDShape called Circle. Include an area() method that computes the area of the circle and a constructor that uses super to initialize the TwoDShape portion.

```java
// A subclass of TwoDShape for circles.
class Circle extends TwoDShape {
    // A default constructor.
    Circle() {
        super();
    }

    // Construct Circle
    Circle(double x) {
        super(x, "circle"); // call superclass constructor
    }

    // Construct an object from an object.
    Circle(Circle ob) {
        super(ob); // pass object to TwoDShape constructor
    }

    double area() {
        return (getWidth() / 2) * (getWidth() / 2) * 4.1416;
    }
}
```

3. How do you prevent a subclass from having access to a member of a superclass?

To prevent a subclass from having access to a superclass member, declare that member as private.

4. Describe the purpose and use of both versions of super.

The super keyword has two forms. The first is used to call a superclass constructor. The general form of this usage is

```
super(param-list);
```

The second form of super is used to access a superclass member. It has this general form:

```
super.member
```
5. Given the following hierarchy, in what order are the constructors for these classes called when a Gamma object is instantiated?

```java
class Alpha { ... 

class Beta extends Alpha { ... 

Class Gamma extends Beta { ... 

Constructors are always called in order of derivation. Thus, when a Gamma object is created, the order is Alpha, Beta, Gamma.
```

6. A superclass reference can refer to a subclass object. Explain why this is important as it is related to method overriding.

When an overridden method is called through a superclass reference, it is the type of the object being referred to that determines which version of the method is called.

7. What is an abstract class?

An abstract class contains at least one abstract method.

8. How do you prevent a method from being overridden? How do you prevent a class from being inherited?

To prevent a method from being overridden, declare it as `final`. To prevent a class from being inherited, declare it as `final`.

9. Explain how inheritance, method overriding, and abstract classes are used to support polymorphism?

Inheritance, method overriding, and abstract classes support polymorphism by enabling you to create a generalized class structure that can be implemented by a variety of classes. Thus, the abstract class defines a consistent interface which is shared by all implemented classes. This embodies the concept of “one interface, multiple methods.”

10. What class is a superclass of every other class?

   The `Object` class

11. A class that contains at least one abstract method must, itself, be declared abstract. True or False?

   True.

12. What keyword is used to create a named constant?

   `final`
Module 8: Packages and Interfaces

1. Using the code from Project 8-1, put the ICharQ interface and its three implementations into a package called QPack. Keeping the queue demonstration class IQDemo in the default package, show how to import and use the classes in QPack.

To put ICharQ and its implementations into the QPack package, you must separate each into its own file, make each implementation class public, and add this statement to the top of each file.

```java
package QPack;
```

Once this has been done, you can use QPack by adding this import statement to IQDemo.

```java
import QPack.*;
```

2. What is a namespace? Why is it important that Java allows you to partition the namespace?

A namespace is a declarative region. By partitioning the namespace, you can prevent name collisions.

3. Packages are stored in directories.

4. Explain the difference between protected and default access.

A member with protected access can be used within its package and by a subclass in any package. A member with default access can be used only within its package.

5. Explain the two ways that the members of a package can be used by other packages.

To use a member of a package, you can either fully qualify its name, or you can import it using import.

6. “One interface, multiple methods” is a key tenet of Java. What feature best exemplifies it?

The interface best exemplifies the one interface, multiple methods principle of OOP.

7. How many classes can implement an interface? How many interfaces can a class implement?

An interface can be implemented by an unlimited number of classes. A class can implement as many interfaces as it chooses.

8. Can interfaces be extended?

Yes, interfaces can be extended.

9. Create an interface for the Vehicle class from Module 7. Call the interface IVehicle.

```java
interface IVehicle {

    // Return the range.
}
```
int range();

// Compute fuel needed for a given distance.
double fuelneeded(int miles);

// Access methods for instance variables.
int getPassengers();
void setPassengers(int p);
int getFuelcap();
void setFuelcap(int f);
int getMpg();
void setMpg(int m);
}

10. Variables declared in an interface are implicitly static and final. What good are they?

Interface variables are valuable as named constants that are shared by all files in a program. They are brought into view by importing their interface.

11. A package is, in essence, a container for classes. True or False?

True.

12. What standard Java package is automatically imported into a program?

java.lang

Module 9: Exception Handling

1. What class is at the top of the exception hierarchy?

Throwable is at the top of the exception hierarchy.

2. Briefly explain how to use try and catch.

The try and catch statements work together. Program statements that you want to monitor for exceptions are contained within a try block. An exception is caught using catch.

3. What is wrong with this fragment?

// ...
vals[18] = 10;
catch (ArrayIndexOutOfBoundsException exc) {
    // handle error
}

There is no try block preceding the catch statement.
4. What happens if an exception is not caught?

If an exception is not caught, abnormal program termination results.

5. What is wrong with this fragment?

```java
class A extends Exception { ... 

class B extends A { ... 

// ... 

try {
    // ...
}
catch (A exc) { ... }
catch (B exc) { ... }
```

In the fragment, a superclass `catch` precedes a subclass `catch`. Since the superclass `catch` will catch all subclasses too, unreachable code is created.

6. Can an exception caught by an inner `catch` rethrow that exception to an outer `catch`?

Yes, an exception can be rethrown.

7. The `finally` block is the last bit of code executed before your program ends. True or false? Explain your answer.

False. The `finally` block is the code executed when a `try` block ends.

8. What type of exceptions must be explicitly declared in a `throws` clause of a method?

All exceptions except those of type `RuntimeException` and `Error` must be declared in a `throws` clause.

9. What is wrong with this fragment?

```java
class MyClass { // ... 
    // ... 
    throw new MyClass(); 
```

`MyClass` does not extend `Throwable`. Only subclasses of `Throwable` can be thrown by `throw`.

10. In question 3 of the Mastery Check in Module 6, you created a `Stack` class. Add custom exceptions to your class that report stack full and stack empty conditions.

```java
// An exception for stack-full errors.
class StackFullException extends Exception {
    int size;

    StackFullException(int s) { size = s; }

    public String toString() {
        return "\nStack is full. Maximum size is " +
```
size;
}
}

// An exception for stack-empty errors.
class StackEmptyException extends Exception {

    public String toString() {
        return "\nStack is empty.";
    }
}

// A stack class for characters.
class Stack {
    private char stck[]; // this array holds the stack
    private int tos;   // top of stack

    // Construct an empty Stack given its size.
    Stack(int size) {
        stck = new char[size]; // allocate memory for stack
        tos = 0;
    }

    // Construct a Stack from a Stack.
    Stack(Stack ob) {
        tos = ob.tos;
        stck = new char[ob.stck.length];

        // copy elements
        for(int i=0; i < tos; i++)
            stck[i] = ob.stck[i];
    }

    // Construct a stack with initial values.
    Stack(char a[]) {
        stck = new char[a.length];

        for(int i = 0; i < a.length; i++) {
            try {
                push(a[i]);
            } catch(StackFullException exc) {
                System.out.println(exc);
            }
        }
    }

    // Push characters onto the stack.
Appendix A: Answers to Mastery Checks

```java
void push(char ch) throws StackFullException {
    if (tos == stck.length)
        throw new StackFullException(stck.length);

    stck[tos] = ch;
    tos++;
}

// Pop a character from the stack.
char pop() throws StackEmptyException {
    if (tos == 0)
        throw new StackEmptyException();

    tos--;
    return stck[tos];
}
```

11. What are the three ways that an exception can be generated?

An exception can be generated by an error in the JVM, an error in your program, or explicitly via a `throw` statement.

12. What are the two direct subclasses of `Throwable`?

`Error` and `Exception`

Module 10: Using I/O

1. Why does Java define both byte and character streams?

The byte streams are the original streams defined by Java. They are especially useful for binary I/O, and they support random access files. The character streams are optimized for Unicode.

2. Even though console input and output is text-based, why does Java still use byte streams for this purpose?

The predefined streams, `System.in`, `System.out`, and `System.err`, were defined before Java added the character streams.

3. Show how to open a file for reading bytes.

Here is one way to open a file for byte input:

```java
FileInputStream fin = new FileInputStream("test");
```

4. Show how to open a file for reading characters.

Here is one way to open a file for reading characters:

```java
FileReader fr = new FileReader("test");
```
5. Show how to open a file for random access I/O.

Here is one way to open a file for random access:
```
randfile = new RandomAccessFile("test", "rw");
```

6. How do you convert a numeric string such as "123.23" into its binary equivalent?

To convert numeric strings into their binary equivalents, use the parsing methods defined by the type wrappers, such as `Integer` or `Double`.

7. Write a program that copies a text file. In the process, have it convert all spaces into hyphens. Use the byte stream file classes.

```
/* Copy a text file, substituting hyphens for spaces.

This version uses byte streams.

To use this program, specify the name of the source file and the destination file.
For example,

    java Hyphen source target
*/

import java.io.*;

class Hyphen {
    public static void main(String args[])
        throws IOException
    {
        int i;
        FileInputStream fin;
        FileOutputStream fout;

        try {
            // open input file
            try {
                fin = new FileInputStream(args[0]);
            } catch(FileNotFoundException exc) {
                System.out.println("Input File Not Found");
                return;
            }

            // open output file
            try {
                fout = new FileOutputStream(args[1]);
            } catch(FileNotFoundException exc) {
                System.out.println("Error Opening Output File");
            }
```
8. Rewrite the program in question 7 so that it uses the character stream classes.

/* Copy a text file, substituting hyphens for spaces.

This version uses character streams.

To use this program, specify the name of the source file and the destination file.
For example,

java Hyphen2 source target
*/

import java.io.*;

class Hyphen2 {
    public static void main(String args[])
        throws IOException
    {
        int i;
        FileReader fin;
        FileWriter fout;

        try {
            // open input file
            fin = new FileReader(fin);  
            fout = new FileWriter(fout);

            try {
                do {
                    i = fin.read();
                    if((char)i == ' ') i = '-';
                    if(i != -1) fout.write(i);
                } while(i != -1);
            } catch(ArrayIndexOutOfBoundsException exc) {
                System.out.println("Usage: Hyphen From To");
                return;
            }
        } catch(IOException exc) {
            System.out.println("File Error");
        }

        fin.close();
        fout.close();
    }
}
try {
    fin = new FileReader(args[0]);
} catch(FileNotFoundException exc) {
    System.out.println("Input File Not Found");
    return;
}

// open output file
try {
    fout = new FileWriter(args[1]);
} catch(IOException exc) {
    System.out.println("Error Opening Output File");
    return;
}
} catch(ArrayIndexOutOfBoundsException exc) {
    System.out.println("Usage: Hyphen2 From To");
    return;
}

// Copy File
try {
    try {
        do {
            i = fin.read();
            if((char)i == ' ') i = '-';
            if(i != -1) fout.write(i);
        } while(i != -1);
    } catch(IOException exc) {
        System.out.println("File Error");
    }

    fin.close();
    fout.close();
}
}

9. What type of stream is System.in?

InputStream

10. What does the read() method of InputStream return when the end of the stream is reached?

-1

11. What type of stream is used to read binary data?

DataInputStream

12. Reader and Writer are at the top of the __________ class hierarchies.

character-based I/O
Module 11: Multithreaded Programming

1. Why does Java’s multithreading capability enable you to write more efficient programs?

Multithreading allows you to take advantage of the idle time that is present in nearly all programs. The essence of multithreading is that when one thread can’t run, another can.

2. Multithreading is supported by the ________ class and the ________ interface.

Multithreading is supported by the Thread class and the Runnable interface.

3. When creating a runnable object, why might you want to extend Thread rather than implement Runnable?

You will extend Thread when you want to override one or more of Thread’s methods other than run().

4. Show how to use join() to wait for a thread object called MyThrd to end.

MyThrd.join();

5. Show how to set a thread called MyThrd to three levels above normal priority.

MyThrd.setPriority(Thread.NORM_PRIORITY+3);

6. What is the effect of adding the synchronized keyword to a method?

Adding synchronized to a method allows only one thread at a time to use the method for any given object of its class.

7. The wait() and notify() methods are used to perform _________________.

The wait() and notify() methods are used to perform interthread communication.

8. Change the TickTock class so that it actually keeps time. That is, have each tick take one half second, and each tock take one half second. Thus, each tick-tock will take one second. (Don’t worry about the time it takes to switch tasks, etc.)

To make the TickTock class actually keep time, simply add calls to sleep(), as shown here.

// Make the TickTock class actually keep time.

class TickTock {

    synchronized void tick(boolean running) {
        if(!running) { // stop the clock
            notify(); // notify any waiting threads
            return;
        }

        System.out.print("Tick ");
    }
}
// wait 1/2 second
try {
    Thread.sleep(500);
} catch(InterruptedException exc) {
    System.out.println("Thread interrupted.");
}

notify(); // let tock() run
try {
    wait(); // wait for tock() to complete
} catch(InterruptedException exc) {
    System.out.println("Thread interrupted.");
}
}

synchronized void tock(boolean running) {
    if(!running) { // stop the clock
        notify(); // notify any waiting threads
        return;
    }

    System.out.println("Tock");

    // wait 1/2 second
    try {
        Thread.sleep(500);
    } catch(InterruptedException exc) {
        System.out.println("Thread interrupted.");
    }

    notify(); // let tick() run
    try {
        wait(); // wait for tick to complete
    } catch(InterruptedException exc) {
        System.out.println("Thread interrupted.");
    }
}

9. Why can’t you use suspend(), resume(), and stop() for new programs?

The suspend(), resume(), and stop() methods have been deprecated because they can cause serious run-time problems.
10. What method defined by Thread obtains the name of a thread?

   getName()

11. What does isAlive() return?

   It returns true if the invoking thread is still running, and false if it has been terminated.

Module 12: Applets, Events, and Miscellaneous Topics

1. What method is called when an applet first begins running? What method is called when an applet is removed from the system?

   When an applet begins, the first method called is init(). When an applet is removed, destroy() is called.

2. Explain why an applet must use multithreading if it needs to run continually.

   An applet must use multithreading if it needs to run continually because applets are event-driven programs which must not enter a “mode” of operation. For example, if start() never returns, then paint() will never be called.

3. Enhance Project 12-1 so that it displays the string passed to it as a parameter. Add a second parameter that specifies the time delay (in milliseconds) between each rotation.

   /* A simple banner applet that uses parameters. */

   import java.awt.*;
   import java.applet.*;
   /*
      <applet code="ParamBanner" width=300 height=50>
      <param name=message value=" I like Java! ">
      <param name=delay value=500>
      </applet>
   */

   public class ParamBanner extends Applet implements Runnable {
      String msg;
      int delay;
      Thread t;
      boolean stopFlag;
      // Initialize t to null.
      public void init() {
         String temp;
         msg = getParameter("message");

         msg = getParameter("message");
if (msg == null) msg = "Java Rules the Web";

temp = getParameter("delay");
try {
    if (temp != null)
        delay = Integer.parseInt(temp);
    else
        delay = 250; // default if not specified
} catch (NumberFormatException exc) {
    delay = 250; // default on error
}

t = null;
}

// Start thread
public void start() {
    t = new Thread(this);
    stopFlag = false;
    t.start();
}

// Entry point for the thread that runs the banner.
public void run() {
    char ch;

    // Display banner
    for( ; ; ) {
        try {
            repaint();
            Thread.sleep(delay);
            ch = msg.charAt(0);
            msg = msg.substring(1, msg.length());
            msg += ch;
            if (stopFlag)
                break;
        } catch (InterruptedException exc) {}
    }
}

// Pause the banner.
public void stop() {
    stopFlag = true;
    t = null;
}
// Display the banner.
public void paint(Graphics g) {
    g.drawString(msg, 50, 30);
}

4. Extra challenge: Create an applet that displays the current time, updated once per second. To accomplish this, you will need to do a little research. Here is a hint to help you get started: The easiest way to obtain the current time is to use a Calendar object, which is part of the java.util package. (Remember, Sun provides online documentation for all of Java’s standard classes.) You should now be at the point where you can examine the Calendar class on your own and use its methods to solve this problem.

// A simple clock applet.

import java.util.*;
import java.awt.*;
import java.applet.*;

/*
<object code="Clock" width=200 height=50>
</object>
*/

public class Clock extends Applet implements Runnable {
    String msg;
    Thread t;
    Calendar clock;

    boolean stopFlag;

    // Initialize
    public void init() {
        t = null;
        msg = "";
    }

    // Start thread
    public void start() {
        t = new Thread(this);
        stopFlag = false;
        t.start();
    }

    // Entry point for the clock.
    public void run() {
        // Display clock

for( ; ; ) {
    try {
        clock = Calendar.getInstance();
        msg = "Current time is " +
            Integer.toString(clock.get(Calendar.HOUR));
        msg = msg + ":" +
            Integer.toString(clock.get(Calendar.MINUTE));
        msg = msg + ":" +
            Integer.toString(clock.get(Calendar.SECOND));
        repaint();
        Thread.sleep(1000);
        if(stopFlag)
            break;
    } catch(InterruptedException exc) {}
}

// Pause the clock.
public void stop() {
    stopFlag = true;
    t = null;
}

// Display the clock.
public void paint(Graphics g) {
    g.drawString(msg, 30, 30);
}

5. Briefly explain Java’s delegation event model.

In the delegation event model, a source generates an event and sends it to one or more listeners. A listener simply waits until it receives an event. Once received, the listener processes the event and then returns.

6. Must an event listener register itself with a source?

Yes; a listener must register with a source to receive events.

7. Extra challenge: Another of Java’s display methods is drawLine(). It draws a line in the currently selected color between two points. It is part of the Graphics class. Using drawLine(), write a program that tracks mouse movement. If the button is pressed, have the program draw a continuous line until the mouse button is released.

/* Track mouse motion by drawing a line
    when a mouse button is pressed. */
import java.awt.*;
import java.awt.event.*;
import java.applet.*;

/*
   <applet code="TrackM" width=300 height=100>
   </applet>
*/

public class TrackM extends Applet
    implements MouseListener, MouseMotionListener {

    int curX = 0, curY = 0; // current coordinates
    int oldX = 0, oldY = 0; // previous coordinates
    boolean draw;

    public void init() {
        addMouseListener(this);
        addMouseMotionListener(this);
        draw = false;
    }

    /* The next three methods are not used, but must
     be null-implemented because they are defined
     by MouseListener. */

    // Handle mouse entered.
    public void mouseEntered(MouseEvent me) {
    }

    // Handle mouse exited.
    public void mouseExited(MouseEvent me) {
    }

    // Handle mouse click.
    public void mouseClicked(MouseEvent me) {
    }

    // Handle button pressed.
    public void mousePressed(MouseEvent me) {
        // save coordinates
        oldX = me.getX();
        oldY = me.getY();
        draw = true;
    }

    // Handle button released.

public void mouseReleased(MouseEvent me) {
    draw = false;
}

// Handle mouse dragged.
public void mouseDragged(MouseEvent me) {
    // save coordinates
    curX = me.getX();
    curY = me.getY();
    repaint();
}

// Handle mouse moved.
public void mouseMoved(MouseEvent me) {
    // show status
    showStatus("Moving mouse at " + me.getX() + ", " + me.getY());
}

// Display line in applet window.
public void paint(Graphics g) {
    if(draw)
        g.drawLine(oldX, oldY, curX, curY);
}

8. Briefly describe the assert keyword.

The assert keyword creates an assertion, which is a condition that should be true during program execution. If the assertion is false, an AssertionError is thrown.

9. Give one reason why a native method might be useful to some types of programs.

A native method is useful when interfacing to routines written in languages other than Java, or when optimizing code for a specific run-time environment.
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Appendix B

Using Java’s Documentation Comments
As explained in Module 1, 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 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 generated with javadoc, because that is the way the Java API library was documented by Sun.

The javadoc Tags

The javadoc utility recognizes the following tags:

<table>
<thead>
<tr>
<th>Tag</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>@author</td>
<td>Identifies the author of a class.</td>
</tr>
<tr>
<td>@deprecated</td>
<td>Specifies that a class or member is deprecated.</td>
</tr>
<tr>
<td>@docRoot</td>
<td>Specifies the path to the root directory of the current documentation. (Added by Java 2, version 1.3.)</td>
</tr>
<tr>
<td>@exception</td>
<td>Identifies an exception thrown by a method.</td>
</tr>
<tr>
<td>@inheritDoc</td>
<td>Inherits a comment from the immediate superclass. (Added by Java 2, version 1.4, but not currently implemented.)</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. (Added by Java 2, version 1.4.)</td>
</tr>
<tr>
<td>@param</td>
<td>Documents a method’s parameter.</td>
</tr>
<tr>
<td>@return</td>
<td>Documents a method’s return value.</td>
</tr>
<tr>
<td>@see</td>
<td>Specifies a link to another topic.</td>
</tr>
<tr>
<td>@serial</td>
<td>Documents a default serializable field.</td>
</tr>
<tr>
<td>@serialData</td>
<td>Documents the data written by the writeObject() or writeExternal() methods.</td>
</tr>
<tr>
<td>@serialField</td>
<td>Documents an ObjectStreamField component.</td>
</tr>
<tr>
<td>@since</td>
<td>States the release when a specific change was introduced.</td>
</tr>
<tr>
<td>@throws</td>
<td>Same as @exception.</td>
</tr>
<tr>
<td>@value</td>
<td>Displays the value of a constant, which must be a static field. (Added by Java 2, version 1.4.)</td>
</tr>
<tr>
<td>@version</td>
<td>Specifies the version of a class.</td>
</tr>
</tbody>
</table>
As you can see, all document tags begin with an at sign (@). 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.

You can use documentation comments to document classes, interfaces, fields, constructors, and methods. In all cases, the documentation comment must immediately precede the item being documented. When you are documenting a variable, the documentation tags you can use are @see, @since, @serial, @serialField, {@value}, and @deprecated. For classes, you can use @see, @author, @since, @deprecated, and @version. Methods can be documented with @see, @return, @param, @since, @deprecated, @throws, @serialData, {@inheritDoc}, and @exception. A {@link}, {@docRoot}, or {@linkplain} tag can be used anywhere. Each tag is examined next.

@author
The @author tag documents the author of a class. It has the following syntax:

@author description

Here, description will usually be the name of the person who wrote the class. The @author tag can be used only in documentation for a class. You may need to specify the -author option when executing javadoc in order for the @author field to be included in the HTML documentation.

@deprecated
The @deprecated tag specifies that a class or a member is deprecated. It is recommended that you include @see or {@link} tags to inform the programmer about available alternatives. The syntax is the following:

@deprecated description

Here, description is the message that describes the deprecation. Information specified by the @deprecated tag is recognized by the compiler and is included in the .class file that is generated. Therefore, the programmer can be given this information when compiling Java source files. The @deprecated tag can be used in documentation for variables, methods, and classes.

{@docRoot}
{@docRoot} specifies the path to the root directory of the current documentation.
The @exception tag describes an exception to a method. It has the following syntax:

```
@exception exception-name explanation
```

Here, the fully qualified name of the exception is specified by `exception-name`; `explanation` is a string that describes how the exception can occur. The @exception tag can only be used in documentation for a method.

Inherits a comment from the immediate superclass. (Not currently implemented by Java 2, version 1.4.)

The {@link} tag provides an in-line link to additional information. It has the following syntax:

```
{@link name text}
```

Here, `name` is the name of a class or method to which a link is added, and `text` is the string that is displayed.

Inserts an in-line link to another topic. The link is displayed in a plain-text font. Otherwise, it is similar to `{@link}`.

The @param tag documents a parameter to a method. It has the following syntax:

```
@param parameter-name explanation
```

Here, `parameter-name` specifies the name of a parameter to a method. The meaning of that parameter is described by `explanation`. The @param tag can be used only in documentation for a method.
**@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. Its most 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

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 a class or member was introduced in a specific release. It has the following syntax:

@since release

Here, release is a string that designates the release or version in which this feature became available. The @since tag can be used in documentation for variables, methods, and classes.

@throws

The @throws tag has the same meaning as the @exception tag.

{@value}

Displays the value of a constant, which must be a static field.

@version

The @version tag specifies the version of a class. It has the following syntax:

@version info

Here, info is a string that contains version information, typically a version number, such as 2.2. The @version tag can be used only in documentation for a class. You may 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, variable, or method. 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 an asterisk (*) that is 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.

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. Since different implementations of javadoc may work differently, you will need to check the instructions that accompany your Java development system for details specific to your version.

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.

```java
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.
 * @return Nothing.
 * @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);
}
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