```
// A complete implementation of BoxWeight.
class Box {
  private double width;
  private double height;
  private double depth;

  // construct clone of an object
  Box(Box ob) { // pass object to constructor
    width = ob.width;
    height = ob.height;
    depth = ob.depth;
  }

  // constructor used when all dimensions specified
  Box(double w, double h, double d) {
    width = w;
    height = h;
    depth = d;
  }

  // constructor used when no dimensions specified
  Box() {
    width = -1;  // use -1 to indicate
    height = -1; // an uninitialized
    depth = -1;  // box
  }

  // constructor used when cube is created
  Box(double len) {
    width = height = depth = len;
  }

  // compute and return volume
  double volume() {
    return width * height * depth;
  }
 }

// BoxWeight now fully implements all constructors.
class BoxWeight extends Box {
  double weight; // weight of box

  // construct clone of an object
  BoxWeight(BoxWeight ob) { // pass object to constructor
    super(ob);
    weight = ob.weight;
  }

  // constructor when all parameters are specified
  BoxWeight(double w, double h, double d, double m) {
```

```
    super(w, h, d); // call superclass constructor
    weight = m;
  }

  // default constructor
  BoxWeight() {
    super();
    weight = -1;
  }

  // constructor used when cube is created
  BoxWeight(double len, double m) {
    super(len);
    weight = m;
  }
}

class DemoSuper {
  public static void main(String args[]) {
    BoxWeight mybox1 = new BoxWeight(10, 20, 15, 34.3);
    BoxWeight mybox2 = new BoxWeight(2, 3, 4, 0.076);
    BoxWeight mybox3 = new BoxWeight(); // default
    BoxWeight mycube = new BoxWeight(3, 2);
    BoxWeight myclone = new BoxWeight(mybox1);
    double vol;

    vol = mybox1.volume();
    System.out.println("Volume of mybox1 is " + vol);
    System.out.println("Weight of mybox1 is " + mybox1.weight);
    System.out.println();

    vol = mybox2.volume();
    System.out.println("Volume of mybox2 is " + vol);
    System.out.println("Weight of mybox2 is " + mybox2.weight);
    System.out.println();

    vol = mybox3.volume();
    System.out.println("Volume of mybox3 is " + vol);
    System.out.println("Weight of mybox3 is " + mybox3.weight);
    System.out.println();

    vol = myclone.volume();
    System.out.println("Volume of myclone is " + vol);
    System.out.println("Weight of myclone is " + myclone.weight);
    System.out.println();

    vol = mycube.volume();
    System.out.println("Volume of mycube is " + vol);
    System.out.println("Weight of mycube is " + mycube.weight);
    System.out.println();
  }
}
```

This program generates the following output:

```
Volume of mybox1 is 3000.0
Weight of mybox1 is 34.3

Volume of mybox2 is 24.0
Weight of mybox2 is 0.076

Volume of mybox3 is -1.0
Weight of mybox3 is -1.0

Volume of myclone is 3000.0
Weight of myclone is 34.3

Volume of mycube is 27.0
Weight of mycube is 2.0
```

Pay special attention to this constructor in **BoxWeight**:

```
// construct clone of an object
BoxWeight(BoxWeight ob) { // pass object to constructor
  super(ob);
  weight = ob.weight;
}
```

Notice that **super( )** is passed an object of type **BoxWeight**—not of type **Box**. This still invokes the constructor **Box(Box ob)**. As mentioned earlier, a superclass variable can be used to reference any object derived from that class. Thus, we are able to pass a **BoxWeight** object to the **Box** constructor. Of course, **Box** only has knowledge of its own members.

Let's review the key concepts behind **super( )**. When a subclass calls **super( )**, it is calling the constructor of its immediate superclass. Thus, **super( )** always refers to the superclass immediately above the calling class. This is true even in a multileveled hierarchy. Also, **super( )** must always be the first statement executed inside a subclass constructor.

A Second Use for super

The second form of **super** acts somewhat like **this**, except that it always refers to the superclass of the subclass in which it is used. This usage has the following general form:

super.*member*

Here, *member* can be either a method or an instance variable.

This second form of **super** is most applicable to situations in which member names of a subclass hide members by the same name in the superclass. Consider this simple class hierarchy:

```
// Using super to overcome name hiding.
class A {
  int i;
}

// Create a subclass by extending class A.
class B extends A {
  int i; // this i hides the i in A

  B(int a, int b) {
    super.i = a; // i in A
    i = b; // i in B
  }

  void show() {
    System.out.println("i in superclass: " + super.i);
    System.out.println("i in subclass: " + i);
  }
}

class UseSuper {
  public static void main(String args[]) {
    B subOb = new B(1, 2);

    subOb.show();
  }
}
```

This program displays the following:

```
i in superclass: 1
i in subclass: 2
```

Although the instance variable **i** in **B** hides the **i** in **A**, **super** allows access to the **i** defined in the superclass. As you will see, **super** can also be used to call methods that are hidden by a subclass.

Creating a Multilevel Hierarchy

Up to this point, we have been using simple class hierarchies that consist of only a superclass and a subclass. However, you can build hierarchies that contain as many layers of inheritance as you like. As mentioned, it is perfectly acceptable to use a subclass as a superclass of another. For example, given three classes called **A**, **B**, and **C**, **C** can be a subclass of **B**, which is a subclass of **A**. When this type of situation occurs, each subclass inherits all of the traits found in all of its superclasses. In this case, **C** inherits all aspects of **B** and **A**. To see how a multilevel hierarchy can be useful, consider the following program. In it, the subclass **BoxWeight** is used as a superclass to create the subclass called **Shipment**. **Shipment** inherits all of the traits of **BoxWeight** and **Box**, and adds a field called **cost**, which holds the cost of shipping such a parcel.

```
// Extend BoxWeight to include shipping costs.

// Start with Box.
class Box {
  private double width;
  private double height;
  private double depth;
```

```
  // construct clone of an object
  Box(Box ob) { // pass object to constructor
    width = ob.width;
    height = ob.height;
    depth = ob.depth;
  }

  // constructor used when all dimensions specified
  Box(double w, double h, double d) {
    width = w;
    height = h;
    depth = d;
  }

  // constructor used when no dimensions specified
  Box() {
    width = -1;  // use -1 to indicate
    height = -1; // an uninitialized
    depth = -1;  // box
  }

  // constructor used when cube is created
  Box(double len) {
    width = height = depth = len;
  }

  // compute and return volume
  double volume() {
    return width * height * depth;
  }
}

// Add weight.
class BoxWeight extends Box {
  double weight; // weight of box

  // construct clone of an object
  BoxWeight(BoxWeight ob) { // pass object to constructor
    super(ob);
    weight = ob.weight;
  }

  // constructor when all parameters are specified
  BoxWeight(double w, double h, double d, double m) {
    super(w, h, d); // call superclass constructor
    weight = m;
  }

  // default constructor
  BoxWeight() {
    super();
    weight = -1;
  }
```

```
  // constructor used when cube is created
  BoxWeight(double len, double m) {
    super(len);
    weight = m;
  }
}

// Add shipping costs.
class Shipment extends BoxWeight {
  double cost;

  // construct clone of an object
  Shipment(Shipment ob) { // pass object to constructor
    super(ob);
    cost = ob.cost;
  }

  // constructor when all parameters are specified
  Shipment(double w, double h, double d,
           double m, double c) {
    super(w, h, d, m); // call superclass constructor
    cost = c;
  }

  // default constructor
  Shipment() {
    super();
    cost = -1;
  }

  // constructor used when cube is created
  Shipment(double len, double m, double c) {
    super(len, m);
    cost = c;
  }
}

class DemoShipment {
  public static void main(String args[]) {
    Shipment shipment1 =
              new Shipment(10, 20, 15, 10, 3.41);
    Shipment shipment2 =
              new Shipment(2, 3, 4, 0.76, 1.28);

    double vol;

    vol = shipment1.volume();
    System.out.println("Volume of shipment1 is " + vol);
    System.out.println("Weight of shipment1 is "
                       + shipment1.weight);
    System.out.println("Shipping cost: $" + shipment1.cost);
    System.out.println();
```

```
    vol = shipment2.volume();
    System.out.println("Volume of shipment2 is " + vol);
    System.out.println("Weight of shipment2 is "
                       + shipment2.weight);
    System.out.println("Shipping cost: $" + shipment2.cost);
  }
}
```

The output of this program is shown here:

```
Volume of shipment1 is 3000.0
Weight of shipment1 is 10.0
Shipping cost: $3.41

Volume of shipment2 is 24.0
Weight of shipment2 is 0.76
Shipping cost: $1.28
```

Because of inheritance, **Shipment** can make use of the previously defined classes of **Box** and **BoxWeight**, adding only the extra information it needs for its own, specific application. This is part of the value of inheritance; it allows the reuse of code.

This example illustrates one other important point: **super( )** always refers to the constructor in the closest superclass. The **super( )** in **Shipment** calls the constructor in **BoxWeight**. The **super( )** in **BoxWeight** calls the constructor in **Box**. In a class hierarchy, if a superclass constructor requires arguments, then all subclasses must pass those arguments "up the line." This is true whether or not a subclass needs arguments of its own.

NOTE In the preceding program, the entire class hierarchy, including **Box**, **BoxWeight**, and **Shipment**, is shown all in one file. This is for your convenience only. In Java, all three classes could have been placed into their own files and compiled separately. In fact, using separate files is the norm, not the exception, in creating class hierarchies.

When Constructors Are Executed

When a class hierarchy is created, in what order are the constructors for the classes that make up the hierarchy executed? For example, given a subclass called **B** and a superclass called **A**, is **A**'s constructor executed before **B**'s, or vice versa? The answer is that in a class hierarchy, constructors complete their

execution in order of derivation, from superclass to subclass. Further, since **super( )** must be the first statement executed in a subclass' constructor, this order is the same whether or not **super( )** is used. If **super( )** is not used, then the default or parameterless constructor of each superclass will be executed. The following program illustrates when constructors are executed:

```
// Demonstrate when constructors are executed.

// Create a super class.
class A {
  A() {
    System.out.println("Inside A's constructor.");
  }
}

// Create a subclass by extending class A.
class B extends A {
  B() {
    System.out.println("Inside B's constructor.");
  }
}

// Create another subclass by extending B.
class C extends B {
  C() {
    System.out.println("Inside C's constructor.");
  }
}

class CallingCons {
  public static void main(String args[]) {
    C c = new C();
  }
}
```

The output from this program is shown here:

```
Inside A's constructor
Inside B's constructor
Inside C's constructor
```

As you can see, the constructors are executed in order of derivation.

If you think about it, it makes sense that constructors complete their execution in order of derivation. Because a superclass has no knowledge of any subclass, any initialization it needs to perform is separate from and possibly prerequisite to any initialization performed by the subclass. Therefore, it must complete its execution first.

Method Overriding

In a class hierarchy, when a method in a subclass has the same name and type signature as a method in its superclass, then the method in the subclass is said to *override* the method in the superclass. When an overridden method is called from within its subclass, it will always refer to the version of that method defined by the subclass. The version of the method defined by the superclass will be hidden. Consider the following:

```
// Method overriding.
class A {
  int i, j;
  A(int a, int b) {
    i = a;
    j = b;
  }

  // display i and j
  void show() {
    System.out.println("i and j: " + i + " " + j);
  }
}
```

```
class B extends A {
  int k;

  B(int a, int b, int c) {
    super(a, b);
    k = c;
  }

  // display k - this overrides show() in A
  void show() {
    System.out.println("k: " + k);
  }
}

class Override {
  public static void main(String args[]) {
    B subOb = new B(1, 2, 3);

   subOb.show(); // this calls show() in B
  }
}
```

The output produced by this program is shown here:

```
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 wish to access the superclass version of an overridden method, you can do so by using **super**. For example, in this version of **B**, the superclass version of **show( )** is invoked within the subclass' version. This allows all instance variables to be displayed.

```
class B extends A {
  int k;

  B(int a, int b, int c) {
    super(a, b);
    k = c;
  }

  void show() {
    super.show(); // this calls A's show()
    System.out.println("k: " + k);
  }
}
```

If you substitute this version of **A** into the previous program, you will see the following output:

```
i and j: 1 2
k: 3
```

Here, **super.show( )** calls the superclass version of **show( )**.

Method overriding occurs *only* when the names and the type signatures of the two methods are identical. If they are not, then the two methods are simply overloaded. For example, consider this modified version of the preceding example:

```
// Methods with differing type signatures are overloaded - not
// overridden.
class A {
  int i, j;

  A(int a, int b) {
    i = a;
    j = b;
  }

  // display i and j
  void show() {
    System.out.println("i and j: " + i + " " + j);
  }
}

// Create a subclass by extending class A.
class B extends A {
  int k;

  B(int a, int b, int c) {
    super(a, b);
    k = c;
  }

  // overload show()
  void show(String msg) {
    System.out.println(msg + k);
  }
}

class Override {
  public static void main(String args[]) {
    B subOb = new B(1, 2, 3);

    subOb.show("This is k: "); // this calls show() in B
    subOb.show(); // this calls show() in A
  }
}
```

The output produced by this program is shown here:

```
This is k: 3
i and j: 1 2
```

The version of **show( )** in **B** takes a string parameter. This makes its type signature different from the one in **A**, which takes no parameters. Therefore, no overriding (or name hiding) takes place. Instead, the version of **show( )** in **B** simply overloads the version of **show( )** in **A**.

Dynamic Method Dispatch

While the examples in the preceding section demonstrate the mechanics of method overriding, they do not show its power. Indeed, if there were nothing more to method overriding than a name space convention, then it would be, at best, an interesting curiosity, but of little real value. However, this is not the case. Method overriding forms the basis for one of Java's most powerful concepts: *dynamic method dispatch*. Dynamic method dispatch is the mechanism by which a call to an overridden method is resolved at run time, rather than compile time. Dynamic method dispatch is important because this is how Java implements run-time polymorphism.

Let's begin by restating an important principle: a superclass reference variable can refer to a subclass object. Java uses this fact to resolve calls to overridden methods at run time. Here is how. When an overridden method is called through a superclass reference, Java determines which version of that method to execute based upon the type of the object being referred to at the time the call occurs. Thus, this determination is made at run time. When different types of objects are referred to, different versions of an overridden method will be called. In other words, *it is the type of the object being referred to* (not the type of the reference variable) that determines which version of an overridden method will be executed. Therefore, if a superclass contains a method that is overridden by a subclass, then when different types of objects are referred to through a superclass reference variable, different versions of the method are executed.

Here is an example that illustrates dynamic method dispatch:

```
// Dynamic Method Dispatch
class A {
  void callme() {
    System.out.println("Inside A's callme method");
  }
}

class B extends A {
  // override callme()
  void callme() {
    System.out.println("Inside B's callme method");
  }
}

class C extends A {
  // override callme()
  void callme() {
    System.out.println("Inside C's callme method");
  }
}

class Dispatch {
  public static void main(String args[]) {
    A a = new A(); // object of type A
    B b = new B(); // object of type B
    C c = new C(); // object of type C

    A r; // obtain a reference of type A

    r = a; // r refers to an A object
    r.callme(); // calls A's version of callme

    r = b; // r refers to a B object
    r.callme(); // calls B's version of callme

    r = c; // r refers to a C object
    r.callme(); // calls C's version of callme
  }
}
```

The output from the program is shown here:

```
Inside A's callme method
Inside B's callme method
Inside C's callme method
```

This program creates one superclass called **A** and two subclasses of it, called **B** and **C**. Subclasses **B** and **C** override **callme( )** declared in **A**. Inside the **main( )** method, objects of type **A**, **B**, and **C** are declared. Also, a reference of type **A**, called **r**, is declared. The program then in turn assigns a reference to each type of object to **r** and uses that reference to invoke **callme( )**. As the output shows, the version of **callme( )** executed is determined by the type of object being referred to at the time of the call. Had it been determined by the type of the reference variable, **r**, you would see three calls to **A**'s **callme( )** method.

NOTE Readers familiar with C++ or C# will recognize that overridden methods in Java are similar to virtual functions in those languages.

Why Overridden Methods?

As stated earlier, overridden methods allow Java to support run-time polymorphism. Polymorphism is essential to object-oriented programming for one reason: it allows a general class to specify methods that will be common to all of its derivatives, while allowing subclasses to define the specific implementation of some or all of those methods. Overridden methods are another way that Java implements the "one interface, multiple methods" aspect of polymorphism.

Part of the key to successfully applying polymorphism is understanding that the superclasses and subclasses form a hierarchy which moves from lesser to greater specialization. Used correctly, the superclass provides all elements that a subclass can use directly. It also defines those methods that the derived class must implement on its own. This allows the subclass the flexibility to define its own methods, yet still enforces a consistent interface. Thus, by combining inheritance with overridden methods, a superclass can define the general form of the methods that will be used by all of its subclasses.

Dynamic, run-time polymorphism is one of the most powerful mechanisms that object-oriented design brings to bear on code reuse and robustness. The ability of existing code libraries to call methods on instances of new classes without recompiling while maintaining a clean abstract interface is a profoundly powerful tool.

Applying Method Overriding

Let’s look at a more practical example that uses method overriding. The following program creates a superclass called **Figure** that stores the dimensions of a two-dimensional object. It also defines a method called **area( )** that computes the area of an object. The program derives two subclasses from **Figure**. The first is **Rectangle** and the second is **Triangle**. Each of these subclasses overrides **area( )** so that it returns the area of a rectangle and a triangle, respectively.

```
// Using run-time polymorphism.
class Figure {
  double dim1;
  double dim2;

  Figure(double a, double b) {
    dim1 = a;
    dim2 = b;
  }

  double area() {
    System.out.println("Area for Figure is undefined.");
    return 0;
  }
}

class Rectangle extends Figure {
  Rectangle(double a, double b) {
    super(a, b);
  }

  // override area for rectangle
  double area() {
    System.out.println("Inside Area for Rectangle.");
    return dim1 * dim2;
  }
}

class Triangle extends Figure {
  Triangle(double a, double b) {
    super(a, b);
  }

  // override area for right triangle
  double area() {
    System.out.println("Inside Area for Triangle.");
    return dim1 * dim2 / 2;
  }
}

class FindAreas {
  public static void main(String args[]) {
    Figure f = new Figure(10, 10);
    Rectangle r = new Rectangle(9, 5);
```

```
    Triangle t = new Triangle(10, 8);
    Figure figref;

    figref = r;
    System.out.println("Area is " + figref.area());

    figref = t;
    System.out.println("Area is " + figref.area());

    figref = f;
    System.out.println("Area is " + figref.area());
  }
}
```

The output from the program is shown here:

```
Inside Area for Rectangle.
Area is 45
Inside Area for Triangle.
Area is 40
Area for Figure is undefined.
Area is 0
```

Through the dual mechanisms of inheritance and run-time polymorphism, it is possible to define one consistent interface that is used by several different, yet related, types of objects. In this case, if an object is derived from **Figure**, then its area can be obtained by calling **area( )**. The interface to this operation is the same no matter what type of figure is being used.

Using Abstract Classes

There are situations in which you will want to define a superclass that declares the structure of a given abstraction without providing a complete implementation of every method. That is, sometimes you will want to create a superclass that only defines a generalized form that will be shared by all of its subclasses, leaving it to each subclass to fill in the details. Such a class determines the nature of the methods that the subclasses must implement. One way this situation can occur is when a superclass is unable to create a meaningful implementation for a method. This is the case with the class **Figure** used in the preceding example.

The definition of **area( )** is simply a placeholder. It will not compute and display the area of any type of object.

As you will see as you create your own class libraries, it is not uncommon for a method to have no meaningful definition in the context of its superclass. You can handle this situation two ways. One way, as shown in the previous example, is to simply have it report a warning message. While this approach can be useful in certain situations—such as debugging—it is not usually appropriate. You may have methods that must be overridden by the subclass in order for the subclass to have any meaning. Consider the class **Triangle**. It has no meaning if **area( )** is not defined. In this case, you want some way to ensure that a subclass does, indeed, override all necessary methods. Java's solution to this problem is the *abstract method*.

You can require that certain methods be overridden by subclasses by specifying the **abstract** type modifier. These methods are sometimes referred to as *subclasser responsibility* because they have no implementation specified in the superclass. Thus, a subclass must override them—it cannot simply use the version defined in the superclass. To declare an abstract method, use this general form:

abstract *type name*(*parameter-list*);

As you can see, no method body is present.

Any class that contains one or more abstract methods must also be declared abstract. To declare a class abstract, you simply use the **abstract** keyword in front of the **class** keyword at the beginning of the class declaration. There can be no objects of an abstract class. That is, an abstract class cannot be directly instantiated with the **new** operator. Such objects would be useless, because an abstract class is not fully defined. Also, you cannot declare abstract constructors, or abstract static methods. Any subclass of an abstract class must either implement all of the abstract methods in the superclass, or be declared **abstract** itself.

Here is a simple example of a class with an abstract method, followed by a class which implements that method:

```
// A Simple demonstration of abstract.
abstract class A {
  abstract void callme();

  // concrete methods are still allowed in abstract classes
  void callmetoo() {
    System.out.println("This is a concrete method.");
  }
}

class B extends A {
  void callme() {
    System.out.println("B's implementation of callme.");
  }
}

class AbstractDemo {
  public static void main(String args[]) {
    B b = new B();

    b.callme();
    b.callmetoo();
  }
}
```

Notice that no objects of class **A** are declared in the program. As mentioned, it is not possible to instantiate an abstract class. One other point: class **A** implements a concrete method called **callmetoo( )**. This is perfectly acceptable. Abstract classes can include as much implementation as they see fit.

Although abstract classes cannot be used to instantiate objects, they can be used to create object references, because Java's approach to run-time polymorphism is implemented through the use of superclass references. Thus, it must be possible to create a reference to an abstract class so that it can be used to point to a subclass object. You will see this feature put to use in the next example.

Using an abstract class, you can improve the **Figure** class shown earlier. Since there is no meaningful concept of area for an undefined two-dimensional figure, the following version of the program declares **area( )** as abstract inside **Figure**. This, of course, means that all classes derived from **Figure** must

override **area( )**.

```
// Using abstract methods and classes.
abstract class Figure {
  double dim1;
  double dim2;

  Figure(double a, double b) {
    dim1 = a;
    dim2 = b;
  }

  // area is now an abstract method
  abstract double area();
}

class Rectangle extends Figure {
  Rectangle(double a, double b) {
    super(a, b);
  }

  // override area for rectangle
  double area() {
    System.out.println("Inside Area for Rectangle.");
    return dim1 * dim2;
  }
}

class Triangle extends Figure {
  Triangle(double a, double b) {
    super(a, b);
  }

  // override area for right triangle
  double area() {
    System.out.println("Inside Area for Triangle.");
    return dim1 * dim2 / 2;
  }
}

class AbstractAreas {
  public static void main(String args[]) {
  // Figure f = new Figure(10, 10); // illegal now
    Rectangle r = new Rectangle(9, 5);
    Triangle t = new Triangle(10, 8);
    Figure figref; // this is OK, no object is created

    figref = r;
    System.out.println("Area is " + figref.area());
```

```
    figref = t;
    System.out.println("Area is " + figref.area());
  }
}
```

As the comment inside **main( )** indicates, it is no longer possible to declare objects of type **Figure**, since it is now abstract. And, all subclasses of **Figure** must override **area( )**. To prove this to yourself, try creating a subclass that does not override **area( )**. You will receive a compile-time error.

Although it is not possible to create an object of type **Figure**, you can create a reference variable of type **Figure**. The variable **figref** is declared as a reference to **Figure**, which means that it can be used to refer to an object of any class derived from **Figure**. As explained, it is through superclass reference variables that overridden methods are resolved at run time.

Using final with Inheritance

The keyword **final** has three uses. First, it can be used to create the equivalent of a named constant. This use was described in the preceding chapter. The other two uses of **final** apply to inheritance. Both are examined here.

Using final to Prevent Overriding

While method overriding is one of Java's most powerful features, there will be times when you will want to prevent it from occurring. To disallow a method from being overridden, specify **final** as a modifier at the start of its declaration. Methods declared as **final** cannot be overridden. The following fragment illustrates **final**:

```
class A {
  final void meth() {
    System.out.println("This is a final method.");
  }
}

class B extends A {
  void meth() { // ERROR! Can't override.
    System.out.println("Illegal!");
  }
}
```

Because **meth( )** is declared as **final**, it cannot be overridden in **B**. If you attempt to do so, a compile-time error will result.

Methods declared as **final** can sometimes provide a performance enhancement: The compiler is free to *inline* calls to them because it "knows" they will not be overridden by a subclass. When a small **final** method is called, often the Java compiler can copy the bytecode for the subroutine directly inline with the compiled code of the calling method, thus eliminating the costly overhead associated with a method call. Inlining is an option only with **final** methods. Normally, Java resolves calls to methods dynamically, at run time. This is called *late binding*. However, since **final** methods cannot be overridden, a call to one can be resolved at compile time. This is called *early binding*.

Using final to Prevent Inheritance

Sometimes you will want to prevent a class from being inherited. To do this, precede the class declaration with **final**. Declaring a class as **final** implicitly declares all of its methods as **final**, too. As you might expect, it is illegal to declare a class as both **abstract** and **final** since an abstract class is incomplete by itself and relies upon its subclasses to provide complete implementations.

Here is an example of a **final** class:

```
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**.

Local Variable Type Inference and Inheritance

As explained in Chapter 3, JDK 10 added local variable type inference to the Java language, which is supported by the reserved type name **var**. It is important to have a clear understanding of how type inference works within an inheritance hierarchy. Recall that a superclass reference can refer to a derived class object, and this feature is part of Java's support for polymorphism. However, it is critical to remember that, when using local variable type inference, the inferred type of a variable is based on the declared type of its initializer. Therefore, if the initializer is of the superclass type, that will be the inferred type of the variable. It does not matter if the actual object being referred to by the initializer is an instance of a derived class. For example, consider this program:

```
// When working with inheritance, the inferred type is the declared
// type of the initializer, which may not be the most derived type of
// the object being referred to by the initializer.

class MyClass {
  // ...
}

class FirstDerivedClass extends MyClass {
  int x;
  // ...
}

class SecondDerivedClass extends FirstDerivedClass {
  int y;
  // ...
}

class TypeInferenceAndInheritance {
```

```
  // Return some type of MyClass object.
  static MyClass getObj(int which) {
    switch(which) {
      case 0: return new MyClass();
      case 1: return new FirstDerivedClass();
      default: return new SecondDerivedClass();
    }
  }

  public static void main(String args[]) {

    // Even though getObj() returns different types of
    // objects within the MyClass inheritance hierarchy,
    // its declared return type is MyClass. As a result,
    // in all three cases shown here, the type of the
    // variables is inferred to be MyClass, even though
    // different derived types of objects are obtained.

    // Here, getObj() returns a MyClass object.
    var mc = getObj(0);

    // In this case, a FirstDerivedClass object is returned.
    var mc2 = getObj(1);

    // Here, a SecondDerivedClass object is returned.
    var mc3 = getObj(2);

    // Because the types of both mc2 and mc3 are inferred
    // as MyClass (because the return type of getObj() is
    // MyClass), neither mc2 nor mc3 can access the fields
    // declared by FirstDerivedClass or SecondDerivedClass.
//    mc2.x = 10; // Wrong! MyClass does not have an x field.
//    mc3.y = 10; // Wrong! MyClass does not have a y field.
  }
}
```

In the program, a hierarchy is created that consists of three classes, at the top of which is **MyClass**. **FirstDerivedClass** is a subclass of **MyClass**, and **SecondDerivedClass** is a subclass of **FirstDerivedClass**. The program then

uses type inference to create three variables, called **mc**, **mc2**, and **mc3** by calling **getObj( )**. The **getObj( )** method has a return type of **MyClass** (the superclass), but returns objects of type **MyClass**, **FirstDerivedClass**, or **SecondDerivedClass**, depending on the argument that it is passed. As the output shows, the inferred type is determined by the return type of **getObj( )**, not by the actual type of the object obtained. Thus, all three variables will be of type **MyClass**.

The Object Class

There is one special class, **Object**, defined by Java. All other classes are subclasses of **Object**. That is, **Object** is a superclass of all other classes. This means that a reference variable of type **Object** can refer to an object of any other class. Also, since arrays are implemented as classes, a variable of type **Object** can also refer to any array.

Object defines the following methods, which means that they are available in every object.

Method	Purpose
Object clone( )	Creates a new object that is the same as the object being cloned.
boolean equals(Object *object*)	Determines whether one object is equal to another.
void finalize( )	Called before an unused object is recycled. (Deprecated by JDK 9.)
Class<?> getClass( )	Obtains the class of an object at run time.
int hashCode( )	Returns the hash code associated with the invoking object.
void notify( )	Resumes execution of a thread waiting on the invoking object.
void notifyAll( )	Resumes execution of all threads waiting on the invoking object.
String toString( )	Returns a string that describes the object.
void wait( ) void wait(long *milliseconds*) void wait(long *milliseconds*, int *nanoseconds*)	Waits on another thread of execution.

The methods **getClass( )**, **notify( )**, **notifyAll( )**, and **wait( )** are declared as **final**. You may override the others. These methods are described elsewhere in this book. However, notice two methods now: **equals( )** and **toString( )**. The **equals( )** method compares two objects. It returns **true** if the objects are equal, and **false** otherwise. The precise definition of equality can vary, depending on the type of objects being compared. The **toString( )** method returns a string that contains a description of the object on which it is called. Also, this method is automatically called when an object is output using **println( )**. Many classes override this method. Doing so allows them to tailor a description specifically for the types of objects that they create.

One last point: Notice the unusual syntax in the return type for **getClass( )**. This relates to Java's *generics* feature, which is described in Chapter 14.

CHAPTER

Packages and Interfaces

This chapter examines two of Java's most innovative features: packages and interfaces. *Packages* are containers for classes. They are used to keep the class name space compartmentalized. For example, a package allows you to create a class named **List**, which you can store in your own package without concern that it will collide with some other class named **List** stored elsewhere. Packages are stored in a hierarchical manner and are explicitly imported into new class definitions. As you will see in Chapter 16, packages also play an important role with modules.

In previous chapters, you have seen how methods define the interface to the data in a class. Through the use of the **interface** keyword, Java allows you to fully abstract an interface from its implementation. Using **interface**, you can specify a set of methods that can be implemented by one or more classes. In its traditional form, the **interface**, itself, does not actually define any implementation. Although they are similar to abstract classes, **interface**s have an additional capability: A class can implement more than one interface. By contrast, a class can only inherit a single superclass (abstract or otherwise).

Packages

In the preceding chapters, the name of each example class was taken from the same name space. This means that a unique name had to be used for each class to avoid name collisions. After a while, without some way to manage the name space, you could run out of convenient, descriptive names for individual classes. You also need some way to be assured that the name you choose for a class will be reasonably unique and not collide with class names chosen by other programmers. (Imagine a small group of programmers fighting over who gets to use the name "Foobar" as a class name. Or, imagine the entire Internet community arguing over who first named a class "Espresso.") Thankfully, Java provides a mechanism for partitioning the class name space into more manageable chunks. This mechanism is the package. The package is both a naming and a visibility control mechanism. You can define classes inside a package that are not accessible by code outside that package. You can also define

class members that are exposed only to other members of the same package. This allows your classes to have intimate knowledge of each other, but not expose that knowledge to the rest of the world.

Defining a Package

To create a package is quite easy: simply include a **package** command as the first statement in a Java source file. Any classes declared within that file will belong to the specified package. The **package** statement defines a name space in which classes are stored. If you omit the **package** statement, the class names are put into the default package, which has no name. (This is why you haven't had to worry about packages before now.) While the default package is fine for short, sample programs, it is inadequate for real applications. Most of the time, you will define a package for your code.

This is the general form of the **package** statement:

package *pkg*;

Here, *pkg* is the name of the package. For example, the following statement creates a package called **mypackage**:

```
package mypackage;
```

Typically, Java uses file system directories to store packages, and that is the approach assumed by the examples in this book. For example, the **.class** files for any classes you declare to be part of **mypackage** must be stored in a directory called **mypackage**. Remember that case is significant, and the directory name must match the package name exactly.

More than one file can include the same **package** statement. The **package** statement simply specifies to which package the classes defined in a file belong. It does not exclude other classes in other files from being part of that same package. Most real-world packages are spread across many files.

You can create a hierarchy of packages. To do so, simply separate each package name from the one above it by use of a period. The general form of a multileveled package statement is shown here:

package *pkg1*[.*pkg2*[.*pkg3*]];

A package hierarchy must be reflected in the file system of your Java development system. For example, a package declared as

```
package a.b.c;
```

needs to be stored in **a\b\c** in a Windows environment. Be sure to choose your package names carefully. You cannot rename a package without renaming the directory in which the classes are stored.

Finding Packages and CLASSPATH

As just explained, packages are typically mirrored by directories. This raises an important question: How does the Java run-time system know where to look for packages that you create? As it relates to the examples in this chapter, the answer has three parts. First, by default, the Java run-time system uses the current working directory as its starting point. Thus, if your package is in a subdirectory of the current directory, it will be found. Second, you can specify a directory path or paths by setting the **CLASSPATH** environmental variable. Third, you can use the **-classpath** option with **java** and **javac** to specify the path to your classes. It is useful to point out that, beginning with JDK 9, a package can be part of a module, and thus found on the module path. However, a discussion of modules and module paths is deferred until Chapter 16. For now, we will use only class paths.

For example, consider the following package specification:

```
package mypack;
```

In order for a program to find **mypack**, the program can be executed from a directory immediately above **mypack**, or the **CLASSPATH** must be set to include the path to **mypack**, or the **-classpath** option must specify the path to **mypack** when the program is run via **java**.

When the second two options are used, the class path *must not* include **mypack**, itself. It must simply specify the *path to* **mypack**. For example, in a Windows environment, if the path to **mypack** is

```
C:\MyPrograms\Java\mypack
```

then the class path to **mypack** is

```
C:\MyPrograms\Java
```

The easiest way to try the examples shown in this book is to simply create the package directories below your current development directory, put the **.class**

files into the appropriate directories, and then execute the programs from the development directory. This is the approach used in the following example.

A Short Package Example

Keeping the preceding discussion in mind, you can try this simple package:

```
// A simple package
package mypack;

class Balance {
  String name;
  double bal;

  Balance(String n, double b) {
    name = n;
    bal = b;
  }

  void show() {
    if(bal<0)
      System.out.print("--> ");
    System.out.println(name + ": $" + bal);
  }
}

class AccountBalance {
  public static void main(String args[]) {
    Balance current[] = new Balance[3];

    current[0] = new Balance("K. J. Fielding", 123.23);
    current[1] = new Balance("Will Tell", 157.02);
    current[2] = new Balance("Tom Jackson", -12.33);

    for(int i=0; i<3; i++) current[i].show();
  }
}
```

Call this file **AccountBalance.java** and put it in a directory called **mypack**.

Next, compile the file. Make sure that the resulting **.class** file is also in the

mypack directory. Then, try executing the **AccountBalance** class, using the following command line:

```
java mypack.AccountBalance
```

Remember, you will need to be in the directory above **mypack** when you execute this command. (Alternatively, you can use one of the other two options described in the preceding section to specify the path **mypack**.)

As explained, **AccountBalance** is now part of the package **mypack**. This means that it cannot be executed by itself. That is, you cannot use this command line:

```
java AccountBalance
```

AccountBalance must be qualified with its package name.

Packages and Member Access

In the preceding chapters, you learned about various aspects of Java's access control mechanism and its access modifiers. For example, you already know that access to a **private** member of a class is granted only to other members of that class. Packages add another dimension to access control. As you will see, Java provides many levels of protection to allow fine-grained control over the visibility of variables and methods within classes, subclasses, and packages.

Classes and packages are both means of encapsulating and containing the name space and scope of variables and methods. Packages act as containers for classes and other subordinate packages. Classes act as containers for data and code. The class is Java's smallest unit of abstraction. As it relates to the interplay between classes and packages, Java addresses four categories of visibility for class members:

- Subclasses in the same package
- Non-subclasses in the same package
- Subclasses in different packages
- Classes that are neither in the same package nor subclasses

The three access modifiers, **private**, **public**, and **protected**, provide a variety of ways to produce the many levels of access required by these categories. Table 9-1 sums up the interactions.

	Private	No Modifier	Protected	Public
Same class	Yes	Yes	Yes	Yes
Same package subclass	No	Yes	Yes	Yes
Same package non-subclass	No	Yes	Yes	Yes
Different package subclass	No	No	Yes	Yes
Different package non-subclass	No	No	No	Yes

Table 9-1 Class Member Access

While Java's access control mechanism may seem complicated, we can simplify it as follows. Anything declared **public** can be accessed from different classes and different packages. Anything declared **private** cannot be seen outside of its class. When a member does not have an explicit access specification, it is visible to subclasses as well as to other classes in the same package. This is the default access. If you want to allow an element to be seen outside your current package, but only to classes that subclass your class directly, then declare that element **protected**.

Table 9-1 applies only to members of classes. A non-nested class has only two possible access levels: default and public. When a class is declared as **public**, it is accessible outside its package. If a class has default access, then it can only be accessed by other code within its same package. When a class is public, it must be the only public class declared in the file, and the file must have the same name as the class.

NOTE The modules feature can also affect accessibility. Modules are described in Chapter 16.

An Access Example

The following example shows all combinations of the access control modifiers. This example has two packages and five classes. Remember that the classes for the two different packages need to be stored in directories named after their respective packages—in this case, **p1** and **p2**.

The source for the first package defines three classes: **Protection**, **Derived**, and **SamePackage**. The first class defines four **int** variables in each of the legal protection modes. The variable **n** is declared with the default protection, **n_pri** is **private**, **n_pro** is **protected**, and **n_pub** is **public**.

Each subsequent class in this example will try to access the variables in an instance of this class. The lines that will not compile due to access restrictions

are commented out. Before each of these lines is a comment listing the places from which this level of protection would allow access.

The second class, **Derived**, is a subclass of **Protection** in the same package, **p1**. This grants **Derived** access to every variable in **Protection** except for **n_pri**, the **private** one. The third class, **SamePackage**, is not a subclass of **Protection**, but is in the same package and also has access to all but **n_pri**.

This is file **Protection.java**:

```
package p1;

public class Protection {
  int n = 1;
  private int n_pri = 2;
  protected int n_pro = 3;
  public int n_pub = 4;

  public Protection() {
    System.out.println("base constructor");
    System.out.println("n = " + n);
    System.out.println("n_pri = " + n_pri);
    System.out.println("n_pro = " + n_pro);
    System.out.println("n_pub = " + n_pub);
  }
}
```

This is file **Derived.java**:

```
package p1;

class Derived extends Protection {
  Derived() {
    System.out.println("derived constructor");
    System.out.println("n = " + n);

// class only
// System.out.println("n_pri = "4 + n_pri);

   System.out.println("n_pro = " + n_pro);
   System.out.println("n_pub = " + n_pub);
  }
}
```

This is file **SamePackage.java**:

```
package p1;

class SamePackage {
  SamePackage() {

    Protection p = new Protection();
    System.out.println("same package constructor");
    System.out.println("n = " + p.n);

// class only
// System.out.println("n_pri = " + p.n_pri);

   System.out.println("n_pro = " + p.n_pro);
   System.out.println("n_pub = " + p.n_pub);
  }
}
```

Following is the source code for the other package, **p2**. The two classes defined in **p2** cover the other two conditions that are affected by access control. The first class, **Protection2**, is a subclass of **p1.Protection**. This grants access to all of **p1.Protection**'s variables except for **n_pri** (because it is **private**) and **n**, the variable declared with the default protection. Remember, the default only allows access from within the class or the package, not extra-package subclasses.

Finally, the class **OtherPackage** has access to only one variable, **n_pub**, which was declared **public**.

This is file **Protection2.java**:

```
package p2;

class Protection2 extends p1.Protection {
  Protection2() {
    System.out.println("derived other package constructor");

//  class or package only
//  System.out.println("n = " + n);

//  class only
//  System.out.println("n_pri = " + n_pri);

    System.out.println("n_pro = " + n_pro);
    System.out.println("n_pub = " + n_pub);
  }
}
```

This is file **OtherPackage.java**:

```
package p2;

class OtherPackage {
  OtherPackage() {
    p1.Protection p = new p1.Protection();
    System.out.println("other package constructor");

//  class or package only
//  System.out.println("n = " + p.n);

//  class only
//  System.out.println("n_pri = " + p.n_pri);

//  class, subclass or package only
//  System.out.println("n_pro = " + p.n_pro);

    System.out.println("n_pub = " + p.n_pub);
  }
}
```

If you want to try these two packages, here are two test files you can use. The one for package **p1** is shown here:

```
// Demo package p1.
package p1;

// Instantiate the various classes in p1.
public class Demo {
  public static void main(String args[]) {
    Protection ob1 = new Protection();
    Derived ob2 = new Derived();
    SamePackage ob3 = new SamePackage();
  }
}
```

The test file for **p2** is shown next:

```
// Demo package p2.
package p2;

// Instantiate the various classes in p2.
public class Demo {
  public static void main(String args[]) {
    Protection2 ob1 = new Protection2();
    OtherPackage ob2 = new OtherPackage();
  }
}
```

Importing Packages

Given that packages exist and are a good mechanism for compartmentalizing diverse classes from each other, it is easy to see why all of the built-in Java classes are stored in packages. There are no core Java classes in the unnamed default package; all of the standard classes are stored in some named package. Since classes within packages must be fully qualified with their package name or names, it could become tedious to type in the long dot-separated package path name for every class you want to use. For this reason, Java includes the **import** statement to bring certain classes, or entire packages, into visibility. Once imported, a class can be referred to directly, using only its name. The **import** statement is a convenience to the programmer and is not technically needed to write a complete Java program. If you are going to refer to a few dozen classes in your application, however, the **import** statement will save a lot of typing.

In a Java source file, **import** statements occur immediately following the **package** statement (if it exists) and before any class definitions. This is the general form of the **import** statement:

import *pkg1* [.*pkg2*].(*classname* | *);

Here, *pkg1* is the name of a top-level package, and *pkg2* is the name of a subordinate package inside the outer package separated by a dot (**.**). There is no practical limit on the depth of a package hierarchy, except that imposed by the file system. Finally, you specify either an explicit *classname* or a star (*), which indicates that the Java compiler should import the entire package. This code fragment shows both forms in use:

```
import java.util.Date;
import java.io.*;
```

All of the standard Java SE classes included with Java begin with the name **java**. The basic language functions are stored in a package called **java.lang**. Normally, you have to import every package or class that you want to use, but since Java is useless without much of the functionality in **java.lang**, it is implicitly imported by the compiler for all programs. This is equivalent to the following line being at the top of all of your programs:

```
import java.lang.*;
```

If a class with the same name exists in two different packages that you import using the star form, the compiler will remain silent, unless you try to use one of the classes. In that case, you will get a compile-time error and have to explicitly name the class specifying its package.

It must be emphasized that the **import** statement is optional. Any place you use a class name, you can use its *fully qualified name*, which includes its full package hierarchy. For example, this fragment uses an import statement:

```
import java.util.*;
class MyDate extends Date {
}
```

The same example without the **import** statement looks like this:

```
class MyDate extends java.util.Date {
}
```

In this version, **Date** is fully-qualified.

As shown in Table 9-1, when a package is imported, only those items within the package declared as **public** will be available to non-subclasses in the importing code. For example, if you want the **Balance** class of the package **mypack** shown earlier to be available as a stand-alone class for general use outside of **mypack**, then you will need to declare it as **public** and put it into its own file, as shown here:

```
package mypack;

/* Now, the Balance class, its constructor, and its
   show() method are public. This means that they can
   be used by non-subclass code outside their package.
*/
public class Balance {
  String name;
  double bal;

  public Balance(String n, double b) {
    name = n;
    bal = b;
  }

  public void show() {
    if(bal<0)
      System.out.print("--> ");
    System.out.println(name + ": $" + bal);
  }
}
```

As you can see, the **Balance** class is now **public**. Also, its constructor and its **show( )** method are **public**, too. This means that they can be accessed by any type of code outside the **mypack** package. For example, here **TestBalance** imports **mypack** and is then able to make use of the **Balance** class:

```
import mypack.*;

class TestBalance {
  public static void main(String args[]) {

    /* Because Balance is public, you may use Balance
       class and call its constructor. */
    Balance test = new Balance("J. J. Jaspers", 99.88);

    test.show(); // you may also call show()
  }
}
```

As an experiment, remove the **public** specifier from the **Balance** class and then try compiling **TestBalance**. As explained, errors will result.

Interfaces

Using the keyword **interface**, you can fully abstract a class' interface from its implementation. That is, using **interface**, you can specify what a class must do, but not how it does it. Interfaces are syntactically similar to classes, but they lack instance variables, and, as a general rule, their methods are declared without any body. In practice, this means that you can define interfaces that don't make assumptions about how they are implemented. Once it is defined, any number of classes can implement an **interface**. Also, one class can implement any number of interfaces.

To implement an interface, a class must provide the complete set of methods required by the interface. However, each class is free to determine the details of its own implementation. By providing the **interface** keyword, Java allows you to fully utilize the "one interface, multiple methods" aspect of polymorphism.

Interfaces are designed to support dynamic method resolution at run time. Normally, in order for a method to be called from one class to another, both classes need to be present at compile time so the Java compiler can check to ensure that the method signatures are compatible. This requirement by itself makes for a static and nonextensible classing environment. Inevitably in a system like this, functionality gets pushed up higher and higher in the class hierarchy so that the mechanisms will be available to more and more subclasses. Interfaces are designed to avoid this problem. They disconnect the definition of a method or set of methods from the inheritance hierarchy. Since interfaces are in a different hierarchy from classes, it is possible for classes that are unrelated in terms of the class hierarchy to implement the same interface. This is where the real power of interfaces is realized.

Defining an Interface

An interface is defined much like a class. This is a simplified general form of an interface:

```
access interface name {
        return-type method-name1(parameter-list);
        return-type method-name2(parameter-list);

        type final-varname1 = value;
        type final-varname2 = value;
        //...
        return-type method-nameN(parameter-list);
        type final-varnameN = value;
}
```

When no access modifier is included, then default access results, and the interface is only available to other members of the package in which it is declared. When it is declared as **public**, the interface can be used by code outside its package. In this case, the interface must be the only public interface declared in the file, and the file must have the same name as the interface. *name* is the name of the interface, and can be any valid identifier. Notice that the methods that are declared have no bodies. They end with a semicolon after the parameter list. They are, essentially, abstract methods. Each class that includes such an interface must implement all of the methods.

Before continuing an important point needs to be made. JDK 8 added a feature to **interface** that made a significant change to its capabilities. Prior to JDK 8, an interface could not define any implementation whatsoever. This is the type of interface that the preceding simplified form shows, in which no method declaration supplies a body. Thus, prior to JDK 8, an interface could define only "what," but not "how." JDK 8 changed this. Beginning with JDK 8, it is possible to add a *default implementation* to an interface method. Furthermore, JDK 8 also added static interface methods, and beginning with JDK 9, an interface can include private methods. Thus, it is now possible for **interface** to specify some behavior. However, such methods constitute what are, in essence, special-use features, and the original intent behind **interface** still remains. Therefore, as a general rule, you will still often create and use interfaces in which no use is made of these new features. For this reason, we will begin by discussing the interface in its traditional form. The new interface features are described at the end of this chapter.

As the general form shows, variables can be declared inside interface declarations. They are implicitly **final** and **static**, meaning they cannot be

changed by the implementing class. They must also be initialized. All methods and variables are implicitly **public**.

Here is an example of an interface definition. It declares a simple interface that contains one method called **callback( )** that takes a single integer parameter.

```
interface Callback {
  void callback(int param);
}
```

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 required by the interface. The general form of a class that includes the **implements** clause looks like this:

```
class classname [extends superclass] [implements interface [,interface...]] {
  // class-body
}
```

If a class implements more than one interface, the interfaces are separated with a comma. If a class implements two interfaces that declare the same method, then the same method will be used by clients of either interface. The methods that implement an interface must be declared **public**. Also, the type signature of the implementing method must match exactly the type signature specified in the **interface** definition.

Here is a small example class that implements the **Callback** interface shown earlier:

```
class Client implements Callback {
  // Implement Callback's interface
  public void callback(int p) {

    System.out.println("callback called with " + p);
  }
}
```

Notice that **callback( )** is declared using the **public** access modifier.

REMEMBER When you implement an interface method, it must be declared as **public**.

It is both permissible and common for classes that implement interfaces to define additional members of their own. For example, the following version of **Client** implements **callback( )** and adds the method **nonIfaceMeth( )**:

```
class Client implements Callback {
  // Implement Callback's interface
  public void callback(int p) {
    System.out.println("callback called with " + p);
  }

  void nonIfaceMeth() {
    System.out.println("Classes that implement interfaces " +
                       "may also define other members, too.");
  }
}
```

Accessing Implementations Through Interface References

You can declare variables as object references that use an interface rather than a class type. Any instance of any class that implements the declared interface can be referred to by such a variable. When you call a method through one of these references, the correct version will be called based on the actual instance of the interface being referred to. This is one of the key features of interfaces. The method to be executed is looked up dynamically at run time, allowing classes to be created later than the code which calls methods on them. The calling code can dispatch through an interface without having to know anything about the "callee." This process is similar to using a superclass reference to access a subclass object, as described in Chapter 8.

The following example calls the **callback( )** method via an interface reference variable:

```
class TestIface {
  public static void main(String args[]) {
    Callback c = new Client();
    c.callback(42);
  }
}
```

The output of this program is shown here:

```
callback called with 42
```

Notice that variable **c** is declared to be of the interface type **Callback**, yet it was assigned an instance of **Client**. Although **c** can be used to access the **callback( )** method, it cannot access any other members of the **Client** class. An interface reference variable has knowledge only of the methods declared by its **interface** declaration. Thus, **c** could not be used to access **nonIfaceMeth( )** since it is defined by **Client** but not **Callback**.

While the preceding example shows, mechanically, how an interface reference variable can access an implementation object, it does not demonstrate the polymorphic power of such a reference. To sample this usage, first create the second implementation of **Callback**, shown here:

```
// Another implementation of Callback.
class AnotherClient implements Callback {
  // Implement Callback's interface
  public void callback(int p) {
    System.out.println("Another version of callback");
    System.out.println("p squared is " + (p*p));
  }
}
```

Now, try the following class:

```
class TestIface2 {
  public static void main(String args[]) {
    Callback c = new Client();
    AnotherClient ob = new AnotherClient();

    c.callback(42);

    c = ob; // c now refers to AnotherClient object
    c.callback(42);
  }
}
```

The output from this program is shown here:

```
callback called with 42
Another version of callback
p squared is 1764
```

As you can see, the version of **callback( )** that is called is determined by the type of object that **c** refers to at run time. While this is a very simple example, you will see another, more practical one shortly.

Partial Implementations

If a class includes an interface but does not fully implement the methods required by that interface, then that class must be declared as **abstract**. For example:

```
abstract class Incomplete implements Callback {
  int a, b;

  void show() {
    System.out.println(a + " " + b);
  }
  //...
}
```

Here, the class **Incomplete** does not implement **callback( )** and must be declared as **abstract**. Any class that inherits **Incomplete** must implement **callback( )** or be declared **abstract** itself.

Nested Interfaces

An interface can be declared a member of a class or another interface. Such an interface is called a *member interface* or a *nested interface*. A nested interface can be declared as **public**, **private**, or **protected**. This differs from a top-level interface, which must either be declared as **public** or use the default access level, as previously described. When a nested interface is used outside of its enclosing scope, it must be qualified by the name of the class or interface of which it is a member. Thus, outside of the class or interface in which a nested interface is declared, its name must be fully qualified.

Here is an example that demonstrates a nested interface:

```
// A nested interface example.

// This class contains a member interface.
class A {
  // this is a nested interface
  public interface NestedIF {
    boolean isNotNegative(int x);
  }
}

// B implements the nested interface.
class B implements A.NestedIF {
  public boolean isNotNegative(int x) {
    return x < 0 ? false: true;
  }
}

class NestedIFDemo {
  public static void main(String args[]) {

    // use a nested interface reference
    A.NestedIF nif = new B();

    if(nif.isNotNegative(10))
      System.out.println("10 is not negative");
    if(nif.isNotNegative(-12))
      System.out.println("this won't be displayed");
  }
}
```

Notice that **A** defines a member interface called **NestedIF** and that it is declared **public**. Next, **B** implements the nested interface by specifying

```
implements A.NestedIF
```

Notice that the name is fully qualified by the enclosing class' name. Inside the **main( )** method, an **A.NestedIF** reference called **nif** is created, and it is assigned a reference to a **B** object. Because **B** implements **A.NestedIF**, this is legal.

Applying Interfaces

To understand the power of interfaces, let's look at a more practical example. In earlier chapters, you developed a class called **Stack** that implemented a simple fixed-size stack. However, there are many ways to implement a stack. For example, the stack can be of a fixed size or it can be "growable." The stack can also be held in an array, a linked list, a binary tree, and so on. No matter how the stack is implemented, the interface to the stack remains the same. That is, the methods **push( )** and **pop( )** define the interface to the stack independently of the details of the implementation. Because the interface to a stack is separate from its implementation, it is easy to define a stack interface, leaving it to each implementation to define the specifics. Let's look at two examples.

First, here is the interface that defines an integer stack. Put this in a file called **IntStack.java**. This interface will be used by both stack implementations.

```
// Define an integer stack interface.
interface IntStack {
  void push(int item); // store an item
  int pop(); // retrieve an item
}
```

The following program creates a class called **FixedStack** that implements a fixed-length version of an integer stack:

```
// An implementation of IntStack that uses fixed storage.
class FixedStack implements IntStack {
  private int stck[];
  private int tos;

  // allocate and initialize stack
  FixedStack(int size) {
    stck = new int[size];
    tos = -1;
  }

  // Push an item onto the stack
  public void push(int item) {
    if(tos==stck.length-1) // use length member
      System.out.println("Stack is full.");
    else
      stck[++tos] = item;
  }

  // Pop an item from the stack
  public int pop() {
    if(tos < 0) {
      System.out.println("Stack underflow.");
      return 0;
    }
    else
      return stck[tos--];
  }
}

class IFTest {
  public static void main(String args[]) {
    FixedStack mystack1 = new FixedStack(5);
    FixedStack mystack2 = new FixedStack(8);

    // push some numbers onto the stack
    for(int i=0; i<5; i++) mystack1.push(i);
    for(int i=0; i<8; i++) mystack2.push(i);

    // pop those numbers off the stack
    System.out.println("Stack in mystack1:");
    for(int i=0; i<5; i++)
       System.out.println(mystack1.pop());

    System.out.println("Stack in mystack2:");
    for(int i=0; i<8; i++)
       System.out.println(mystack2.pop());
  }
}
```

Following is another implementation of **IntStack** that creates a dynamic stack by use of the same **interface** definition. In this implementation, each stack is constructed with an initial length. If this initial length is exceeded, then the stack is increased in size. Each time more room is needed, the size of the stack is doubled.

```
// Implement a "growable" stack.
class DynStack implements IntStack {
  private int stck[];
  private int tos;

  // allocate and initialize stack
  DynStack(int size) {
    stck = new int[size];
    tos = -1;
  }

  // Push an item onto the stack
  public void push(int item) {
    // if stack is full, allocate a larger stack
    if(tos==stck.length-1) {
      int temp[] = new int[stck.length * 2]; // double size
      for(int i=0; i<stck.length; i++) temp[i] = stck[i];
      stck = temp;
      stck[++tos] = item;
    }
    else
      stck[++tos] = item;
  }

  // Pop an item from the stack
  public int pop() {
    if(tos < 0) {
      System.out.println("Stack underflow.");
      return 0;
    }
    else
      return stck[tos--];
  }
}

class IFTest2 {
  public static void main(String args[]) {
    DynStack mystack1 = new DynStack(5);
    DynStack mystack2 = new DynStack(8);

    // these loops cause each stack to grow
    for(int i=0; i<12; i++) mystack1.push(i);
    for(int i=0; i<20; i++) mystack2.push(i);

    System.out.println("Stack in mystack1:");
    for(int i=0; i<12; i++)
       System.out.println(mystack1.pop());
```

```
    System.out.println("Stack in mystack2:");
    for(int i=0; i<20; i++)
       System.out.println(mystack2.pop());
  }
}
```

The following class uses both the **FixedStack** and **DynStack** implementations. It does so through an interface reference. This means that calls to **push( )** and **pop( )** are resolved at run time rather than at compile time.

```
/* Create an interface variable and
   access stacks through it.
*/
class IFTest3 {
  public static void main(String args[]) {
    IntStack mystack; // create an interface reference variable
    DynStack ds = new DynStack(5);
    FixedStack fs = new FixedStack(8);

    mystack = ds; // load dynamic stack
    // push some numbers onto the stack
    for(int i=0; i<12; i++) mystack.push(i);

    mystack = fs; // load fixed stack
    for(int i=0; i<8; i++) mystack.push(i);

    mystack = ds;
    System.out.println("Values in dynamic stack:");
    for(int i=0; i<12; i++)
       System.out.println(mystack.pop());

    mystack = fs;
    System.out.println("Values in fixed stack:");
    for(int i=0; i<8; i++)
       System.out.println(mystack.pop());
  }
}
```

In this program, **mystack** is a reference to the **IntStack** interface. Thus, when it

refers to **ds**, it uses the versions of **push( )** and **pop( )** defined by the **DynStack** implementation. When it refers to **fs**, it uses the versions of **push( )** and **pop( )** defined by **FixedStack**. As explained, these determinations are made at run time. Accessing multiple implementations of an interface through an interface reference variable is the most powerful way that Java achieves run-time polymorphism.

Variables in Interfaces

You can use interfaces to import shared constants into multiple classes by simply declaring an interface that contains variables that are initialized to the desired values. When you include that interface in a class (that is, when you "implement" the interface), all of those variable names will be in scope as constants. If an interface contains no methods, then any class that includes such an interface doesn't actually implement anything. It is as if that class were importing the constant fields into the class name space as **final** variables. The next example uses this technique to implement an automated "decision maker":

```
import java.util.Random;

interface SharedConstants {
  int NO = 0;
  int YES = 1;
  int MAYBE = 2;
  int LATER = 3;
  int SOON = 4;
  int NEVER = 5;
}

class Question implements SharedConstants {
  Random rand = new Random();
  int ask() {
    int prob = (int) (100 * rand.nextDouble());
    if (prob < 30)
      return NO;            // 30%
    else if (prob < 60)
      return YES;           // 30%
    else if (prob < 75)
      return LATER;         // 15%
    else if (prob < 98)
      return SOON;          // 13%

    else
      return NEVER;         // 2%
  }
}

class AskMe implements SharedConstants {
  static void answer(int result) {
    switch(result) {
      case NO:
        System.out.println("No");
        break;
      case YES:
        System.out.println("Yes");
        break;
      case MAYBE:
        System.out.println("Maybe");
        break;
      case LATER:
        System.out.println("Later");
        break;
      case SOON:
        System.out.println("Soon");
        break;
      case NEVER:
        System.out.println("Never");
        break;
```

```
    }
  }

  public static void main(String args[]) {
    Question q = new Question();

    answer(q.ask());
    answer(q.ask());
    answer(q.ask());
    answer(q.ask());
  }
}
```

Notice that this program makes use of one of Java's standard classes: **Random**. This class provides pseudorandom numbers. It contains several methods that allow you to obtain random numbers in the form required by your program. In this example, the method **nextDouble( )** is used. It returns random numbers in the range 0.0 to 1.0.

In this sample program, the two classes, **Question** and **AskMe**, both implement the **SharedConstants** interface where **NO**, **YES**, **MAYBE**, **SOON**, **LATER**, and **NEVER** are defined. Inside each class, the code refers to these constants as if each class had defined or inherited them directly. Here is the output of a sample run of this program. Note that the results are different each time it is run.

```
Later
Soon
No
Yes
```

NOTE The technique of using an interface to define shared constants, as just described, is controversial. It is described here for completeness.

Interfaces Can Be Extended

One interface can inherit another by use of the keyword **extends**. The syntax is the same as for inheriting classes. When a class implements an interface that inherits another interface, it must provide implementations for all methods required by the interface inheritance chain. Following is an example:

```
// 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().");
  }
}

class IFExtend {
  public static void main(String arg[]) {
    MyClass ob = new MyClass();

    ob.meth1();
    ob.meth2();
    ob.meth3();
  }
}
```

As an experiment, you might want to try removing the implementation for **meth1( )** in **MyClass**. This will cause a compile-time error. As stated earlier, any class that implements an interface must implement all methods required by that

interface, including any that are inherited from other interfaces.

Default Interface Methods

As explained earlier, prior to JDK 8, an interface could not define any implementation whatsoever. This meant that for all previous versions of Java, the methods specified by an interface were abstract, containing no body. This is the traditional form of an interface and is the type of interface that the preceding discussions have used. The release of JDK 8 changed this by adding a new capability to **interface** called the *default method*. A default method lets you define a default implementation for an interface method. In other words, by use of a default method, it is possible for an interface method to provide a body, rather than being abstract. During its development, the default method was also referred to as an *extension method,* and you will likely see both terms used.

A primary motivation for the default method was to provide a means by which interfaces could be expanded without breaking existing code. Recall that there must be implementations for all methods defined by an interface. In the past, if a new method were added to a popular, widely used interface, then the addition of that method would break existing code because no implementation would be found for that new method. The default method solves this problem by supplying an implementation that will be used if no other implementation is explicitly provided. Thus, the addition of a default method will not cause preexisting code to break.

Another motivation for the default method was the desire to specify methods in an interface that are, essentially, optional, depending on how the interface is used. For example, an interface might define a group of methods that act on a sequence of elements. One of these methods might be called **remove( )**, and its purpose is to remove an element from the sequence. However, if the interface is intended to support both modifiable and nonmodifiable sequences, then **remove( )** is essentially optional because it won't be used by nonmodifiable sequences. In the past, a class that implemented a nonmodifiable sequence would have had to define an empty implementation of **remove( )**, even though it was not needed. Today, a default implementation for **remove( )** can be specified in the interface that does nothing (or throws an exception). Providing this default prevents a class used for nonmodifiable sequences from having to define its own, placeholder version of **remove( )**. Thus, by providing a default, the interface makes the implementation of **remove( )** by a class optional.

It is important to point out that the addition of default methods does not

change a key aspect of **interface**: its inability to maintain state information. An interface still cannot have instance variables, for example. Thus, the defining difference between an interface and a class is that a class can maintain state information, but an interface cannot. Furthermore, it is still not possible to create an instance of an interface by itself. It must be implemented by a class. Therefore, even though, beginning with JDK 8, an interface can define default methods, the interface must still be implemented by a class if an instance is to be created.

One last point: As a general rule, default methods constitute a special-purpose feature. Interfaces that you create will still be used primarily to specify *what* and not *how*. However, the inclusion of the default method gives you added flexibility.

Default Method Fundamentals

An interface default method is defined similar to the way a method is defined by a **class**. The primary difference is that the declaration is preceded by the keyword **default**. For example, consider this simple interface:

```
public interface MyIF {
  // This is a "normal" interface method declaration.
  // It does NOT define a default implementation.
  int getNumber();

  // This is a default method. Notice that it provides
  // a default implementation.
  default String getString() {
    return "Default String";
  }
}
```

MyIF declares two methods. The first, **getNumber( )**, is a standard interface method declaration. It defines no implementation whatsoever. The second method is **getString( )**, and it does include a default implementation. In this case, it simply returns the string "Default String". Pay special attention to the way **getString( )** is declared. Its declaration is preceded by the **default** modifier. This syntax can be generalized. To define a default method, precede its declaration with **default**.

Because **getString( )** includes a default implementation, it is not necessary

for an implementing class to override it. In other words, if an implementing class does not provide its own implementation, the default is used. For example, the **MyIFImp** class shown next is perfectly valid:

```
// Implement MyIF.
class MyIFImp implements MyIF {
  // Only getNumber() defined by MyIF needs to be implemented.
  // getString() can be allowed to default.
  public int getNumber() {
    return 100;
  }
}
```

The following code creates an instance of **MyIFImp** and uses it to call both **getNumber( )** and **getString( )**.

```
// Use the default method.
class DefaultMethodDemo {
  public static void main(String args[]) {

    MyIFImp obj = new MyIFImp();

    // Can call getNumber(), because it is explicitly
    // implemented by MyIFImp:
    System.out.println(obj.getNumber());

    // Can also call getString(), because of default
    // implementation:
    System.out.println(obj.getString());
  }
}
```

The output is shown here:

```
100
Default String
```

As you can see, the default implementation of **getString( )** was automatically used. It was not necessary for **MyIFImp** to define it. Thus, for **getString( )**,

implementation by a class is optional. (Of course, its implementation by a class will be *required* if the class uses **getString( )** for some purpose beyond that supported by its default.)

It is both possible and common for an implementing class to define its own implementation of a default method. For example, **MyIFImp2** overrides **getString( )**:

```
class MyIFImp2 implements MyIF {
  // Here, implementations for both getNumber( ) and getString( ) are provided.
  public int getNumber() {
    return 100;
  }

  public String getString() {
    return "This is a different string.";
  }
}
```

Now, when **getString( )** is called, a different string is returned.

A More Practical Example

Although the preceding shows the mechanics of using default methods, it doesn't illustrate their usefulness in a more practical setting. To do this, let's once again return to the **IntStack** interface shown earlier in this chapter. For the sake of discussion, assume that **IntStack** is widely used and many programs rely on it. Further assume that we now want to add a method to **IntStack** that clears the stack, enabling the stack to be re-used. Thus, we want to evolve the **IntStack** interface so that it defines new functionality, but we don't want to break any preexisting code. In the past, this would be impossible, but with the inclusion of default methods, it is now easy to do. For example, the **IntStack** interface can be enhanced like this:

```
interface IntStack {
  void push(int item); // store an item
  int pop(); // retrieve an item

  // Because clear( ) has a default, it need not be
  // implemented by a preexisting class that uses IntStack.
  default void clear() {
    System.out.println("clear() not implemented.");
  }
}
```

Here, the default behavior of **clear( )** simply displays a message indicating that it is not implemented. This is acceptable because no preexisting class that implements **IntStack** would ever call **clear( )** because it was not defined by the earlier version of **IntStack**. However, **clear( )** can be implemented by a new class that implements **IntStack**. Furthermore, **clear( )** needs to be defined by a new implementation only if it is used. Thus, the default method gives you

- a way to gracefully evolve interfaces over time, and
- a way to provide optional functionality without requiring that a class provide a placeholder implementation when that functionality is not needed.

One other point: In real-world code, **clear( )** would have thrown an exception, rather than displaying an error message. Exceptions are described in the next chapter. After working through that material, you might want to try modifying **clear( )** so that its default implementation throws an **UnsupportedOperationException**.

Multiple Inheritance Issues

As explained earlier in this book, Java does not support the multiple inheritance of classes. Now that an interface can include default methods, you might be wondering if an interface can provide a way around this restriction. The answer is, essentially, no. Recall that there is still a key difference between a class and an interface: a class can maintain state information (especially through the use of instance variables), but an interface cannot.

The preceding notwithstanding, default methods do offer a bit of what one would normally associate with the concept of multiple inheritance. For example, you might have a class that implements two interfaces. If each of these interfaces

provides default methods, then some behavior is inherited from both. Thus, to a limited extent, default methods do support multiple inheritance of behavior. As you might guess, in such a situation, it is possible that a name conflict will occur.

For example, assume that two interfaces called **Alpha** and **Beta** are implemented by a class called **MyClass**. What happens if both **Alpha** and **Beta** provide a method called **reset( )** for which both declare a default implementation? Is the version by **Alpha** or the version by **Beta** used by **MyClass**? Or, consider a situation in which **Beta** extends **Alpha**. Which version of the default method is used? Or, what if **MyClass** provides its own implementation of the method? To handle these and other similar types of situations, Java defines a set of rules that resolves such conflicts.

First, in all cases, a class implementation takes priority over an interface default implementation. Thus, if **MyClass** provides an override of the **reset( )** default method, **MyClass**' version is used. This is the case even if **MyClass** implements both **Alpha** and **Beta**. In this case, both defaults are overridden by **MyClass**' implementation.

Second, in cases in which a class implements two interfaces that both have the same default method, but the class does not override that method, then an error will result. Continuing with the example, if **MyClass** implements both **Alpha** and **Beta**, but does not override **reset( )**, then an error will occur.

In cases in which one interface inherits another, with both defining a common default method, the inheriting interface's version of the method takes precedence. Therefore, continuing the example, if **Beta** extends **Alpha**, then **Beta**'s version of **reset( )** will be used.

It is possible to explicitly refer to a default implementation in an inherited interface by using this form of **super**. Its general form is shown here:

InterfaceName.super.*methodName( )*

For example, if **Beta** wants to refer to **Alpha**'s default for **reset( )**, it can use this statement:

```
Alpha.super.reset();
```

Use static Methods in an Interface

Another capability added to **interface** by JDK 8 is the ability to define one or more **static** methods. Like **static** methods in a class, a **static** method defined by an interface can be called independently of any object. Thus, no implementation

of the interface is necessary, and no instance of the interface is required, in order to call a **static** method. Instead, a **static** method is called by specifying the interface name, followed by a period, followed by the method name. Here is the general form:

InterfaceName.*staticMethodName*

Notice that this is similar to the way that a **static** method in a class is called.

The following shows an example of a **static** method in an interface by adding one to **MyIF**, shown in the previous section. The **static** method is **getDefaultNumber( )**. It returns zero.

```
public interface MyIF {
  // This is a "normal" interface method declaration.
  // It does NOT define a default implementation.
  int getNumber();

  // This is a default method. Notice that it provides
  // a default implementation.
  default String getString() {
    return "Default String";
  }

  // This is a static interface method.
  static int getDefaultNumber() {
    return 0;
  }
}
```

The **getDefaultNumber( )** method can be called, as shown here:

```
int defNum = MyIF.getDefaultNumber();
```

As mentioned, no implementation or instance of **MyIF** is required to call **getDefaultNumber( )** because it is **static**.

One last point: **static** interface methods are not inherited by either an implementing class or a subinterface.

Private Interface Methods

Beginning with JDK 9, an interface can include a private method. A private interface method can be called only by a default method or another private method defined by the same interface. Because a private interface method is specified **private**, it cannot be used by code outside the interface in which it is defined. This restriction includes subinterfaces because a private interface method is not inherited by a subinterface.

The key benefit of a private interface method is that it lets two or more default methods use a common piece of code, thus avoiding code duplication. For example, here is another version of the **IntStack** interface that has two default methods called **popNElements( )** and **skipAndPopNElements( )**. The first returns an array that contains the top *N* elements on the stack. The second skips a specified number of elements and then returns an array that contains the next *N* elements. Both use a private method called **getElements( )** to obtain an array of the specified number of elements from the stack.

```
// Another version of IntStack that has a private interface
// method that is used by two default methods.
interface IntStack {
  void push(int item); // store an item
  int pop(); // retrieve an item
```

```
  // A default method that returns an array that contains
  // the top n elements on the stack.
  default int[] popNElements(int n) {
    // Return the requested elements.
    return getElements(n);
  }

  // A default method that returns an array that contains
  // the next n elements on the stack after skipping elements.
  default int[] skipAndPopNElements(int skip, int n) {

    // Skip the specified number of elements.
    getElements(skip);

    // Return the requested elements.
    return getElements(n);
  }

  // A private method that returns an array containing
  // the top n elements on the stack
  private int[] getElements(int n) {
    int[] elements = new int[n];

    for(int i=0; i < n; i++) elements[i] = pop();
    return elements;
  }
}
```

Notice that both **popNElements( )** and **skipAndPopNElements( )** use the private **getElements( )** method to obtain the array to return. This prevents both methods from having to duplicate the same code sequence. Keep in mind that because **getElements( )** is private, it cannot be called by code outside **IntStack**. Thus, its use is limited to the default methods inside **IntStack**. Also, because **getElements( )** uses the **pop( )** method to obtain stack elements, it will automatically call the implementation of **pop( )** provided by the **IntStack** is implementation. Thus, **getElements( )** will work for any stack class that implements **IntStack**.

Although the private interface method is a feature that you will seldom need, in those cases in which you *do* need it, you will find it quite useful.

Final Thoughts on Packages and Interfaces

Although the examples we've included in this book do not make frequent use of packages or interfaces, both of these tools are an important part of the Java programming environment. Virtually all real programs that you write in Java will be contained within packages. A number will probably implement interfaces as well. It is important, therefore, that you be comfortable with their usage.

CHAPTER

10

Exception Handling

This chapter examines Java's exception-handling mechanism. An *exception* is an abnormal condition that arises in a code sequence at run time. In other words, an exception is a run-time error. In computer languages that do not support exception handling, errors must be checked and handled manually—typically through the use of error codes, and so on. This approach is as cumbersome as it is troublesome. Java's exception handling avoids these problems and, in the process, brings run-time error management into the object-oriented world.

Exception-Handling Fundamentals

A Java exception is an object that describes an exceptional (that is, error) condition that has occurred in a piece of code. When an exceptional condition arises, an object representing that exception is created and *thrown* in the method that caused the error. That method may choose to handle the exception itself, or pass it on. Either way, at some point, the exception is *caught* and processed. Exceptions can be generated by the Java run-time system, or they can be manually generated by your code. Exceptions thrown by Java relate to fundamental errors that violate the rules of the Java language or the constraints of the Java execution environment. Manually generated exceptions are typically used to report some error condition to the caller of a method.

Java exception handling is managed via five keywords: **try**, **catch**, **throw**, **throws**, and **finally**. Briefly, here is how they work. Program statements that you want to monitor for exceptions are contained within a **try** block. If an exception occurs within the **try** block, it is thrown. Your code can catch this exception (using **catch**) and handle it in some rational manner. System-generated exceptions are automatically thrown by the Java run-time system. To manually throw an exception, use the keyword **throw**. Any exception that is thrown out of a method must be specified as such by a **throws** clause. Any code that absolutely must be executed after a **try** block completes is put in a **finally** block.

This is the general form of an exception-handling block:

```
try {
    // block of code to monitor for errors
}

catch (ExceptionType1 exOb) {
    // exception handler for ExceptionType1
}

catch (ExceptionType2 exOb) {
    // exception handler for ExceptionType2
}
// ...
finally {
    // block of code to be executed after try block ends
}
```

Here, *ExceptionType* is the type of exception that has occurred. The remainder of this chapter describes how to apply this framework.

NOTE There is another form of the **try** statement that supports *automatic resource management*. This form of **try**, called ***try*-with-resources**, is described in Chapter 13 in the context of managing files because files are some of the most commonly used resources.

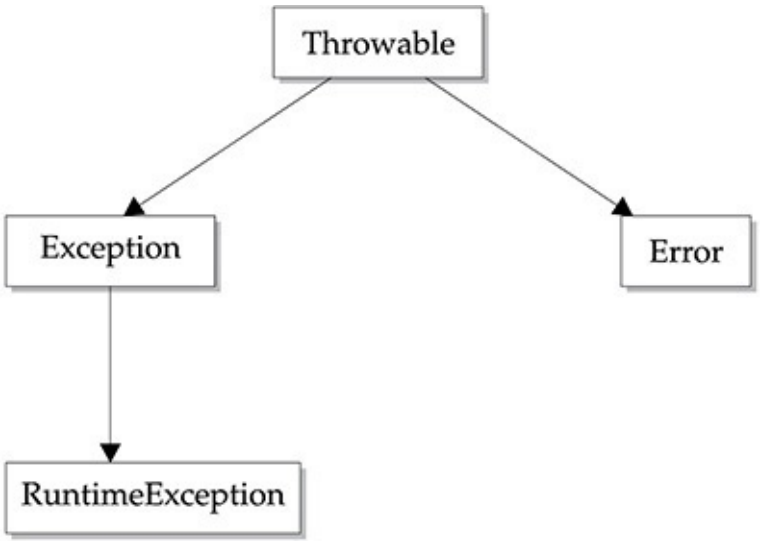
Exception Types

All exception types are subclasses of the built-in class **Throwable**. Thus, **Throwable** is at the top of the exception class hierarchy. Immediately below **Throwable** are two subclasses that partition exceptions into two distinct branches. One branch is headed by **Exception**. This class is used for exceptional conditions that user programs should catch. This is also the class that you will subclass to create your own custom exception types. There is an important subclass of **Exception**, called **RuntimeException**. Exceptions of this type are automatically defined for the programs that you write and include things such as division by zero and invalid array indexing.

The other branch is topped by **Error**, which defines exceptions that are not expected to be caught under normal circumstances by your program. Exceptions

of type **Error** are used by the Java run-time system to indicate errors having to do with the run-time environment, itself. Stack overflow is an example of such an error. This chapter will not be dealing with exceptions of type **Error**, because these are typically created in response to catastrophic failures that cannot usually be handled by your program.

The top-level exception hierarchy is shown here:



Uncaught Exceptions

Before you learn how to handle exceptions in your program, it is useful to see what happens when you don't handle them. This small program includes an expression that intentionally causes a divide-by-zero error:

```
class Exc0 {
  public static void main(String args[]) {
    int d = 0;
    int a = 42 / d;
  }
}
```

When the Java run-time system detects the attempt to divide by zero, it constructs a new exception object and then *throws* this exception. This causes the execution of **Exc0** to stop, because once an exception has been thrown, it must be *caught* by an exception handler and dealt with immediately. In this example, we haven't supplied any exception handlers of our own, so the

exception is caught by the default handler provided by the Java run-time system. Any exception that is not caught by your program will ultimately be processed by the default handler. The default handler displays a string describing the exception, prints a stack trace from the point at which the exception occurred, and terminates the program.

Here is the exception generated when this example is executed:

```
java.lang.ArithmeticException: / by zero
        at Exc0.main(Exc0.java:4)
```

Notice how the class name, **Exc0**; the method name, **main**; the filename, **Exc0.java**; and the line number, **4**, are all included in the simple stack trace. Also, notice that the type of exception thrown is a subclass of **Exception** called **ArithmeticException**, which more specifically describes what type of error happened. As discussed later in this chapter, Java supplies several built-in exception types that match the various sorts of run-time errors that can be generated. One other point: The exact output you see when running this and other example programs in this chapter that use Java's built-in exceptions may vary slightly from what is shown because of differences between JDKs.

The stack trace will always show the sequence of method invocations that led up to the error. For example, here is another version of the preceding program that introduces the same error but in a method separate from **main( )**:

```
class Exc1 {
  static void subroutine() {
    int d = 0;
    int a = 10 / d;
  }
  public static void main(String args[]) {
    Exc1.subroutine();
  }
}
```

The resulting stack trace from the default exception handler shows how the entire call stack is displayed:

```
java.lang.ArithmeticException: / by zero
    at Exc1.subroutine(Exc1.java:4)
    at Exc1.main(Exc1.java:7)
```

As you can see, the bottom of the stack is **main**'s line 7, which is the call to **subroutine( )**, which caused the exception at line 4. The call stack is quite useful for debugging, because it pinpoints the precise sequence of steps that led to the error.

Using try and catch

Although the default exception handler provided by the Java run-time system is useful for debugging, you will usually want to handle an exception yourself. Doing so provides two benefits. First, it allows you to fix the error. Second, it prevents the program from automatically terminating. Most users would be confused (to say the least) if your program stopped running and printed a stack trace whenever an error occurred! Fortunately, it is quite easy to prevent this.

To guard against and handle a run-time error, simply enclose the code that you want to monitor inside a **try** block. Immediately following the **try** block, include a **catch** clause that specifies the exception type that you wish to catch. To illustrate how easily this can be done, the following program includes a **try** block and a **catch** clause that processes the **ArithmeticException** generated by the division-by-zero error:

```
class Exc2 {
  public static void main(String args[]) {
    int d, a;

    try { // monitor a block of code.
     d = 0;
     a = 42 / d;
     System.out.println("This will not be printed.");
    } catch (ArithmeticException e) { // catch divide-by-zero error
     System.out.println("Division by zero.");
    }

    System.out.println("After catch statement.");
  }
}
```

This program generates the following output:

```
Division by zero.
After catch statement.
```

Notice that the call to **println( )** inside the **try** block is never executed. Once an exception is thrown, program control transfers out of the **try** block into the **catch** block. Put differently, **catch** is not “called,” so execution never “returns” to the **try** block from a **catch**. Thus, the line "This will not be printed." is not displayed. Once the **catch** statement has executed, program control continues with the next line in the program following the entire **try / catch** mechanism.

A **try** and its **catch** statement form a unit. The scope of the **catch** clause is restricted to those statements specified by the immediately preceding **try** statement. A **catch** statement cannot catch an exception thrown by another **try** statement (except in the case of nested **try** statements, described shortly). The statements that are protected by **try** must be surrounded by curly braces. (That is, they must be within a block.) You cannot use **try** on a single statement.

The goal of most well-constructed **catch** clauses should be to resolve the exceptional condition and then continue on as if the error had never happened. For example, in the next program each iteration of the **for** loop obtains two random integers. Those two integers are divided by each other, and the result is used to divide the value 12345. The final result is put into **a**. If either division operation causes a divide-by-zero error, it is caught, the value of **a** is set to zero, and the program continues.

```
// Handle an exception and move on.
import java.util.Random;

class HandleError {
  public static void main(String args[]) {
    int a=0, b=0, c=0;
    Random r = new Random();

    for(int i=0; i<32000; i++) {
      try {
        b = r.nextInt();
        c = r.nextInt();
        a = 12345 / (b/c);
      } catch (ArithmeticException e) {
        System.out.println("Division by zero.");
        a = 0; // set a to zero and continue
      }
      System.out.println("a: " + a);
    }
  }
}
```

Displaying a Description of an Exception

Throwable overrides the **toString( )** method (defined by **Object**) so that it returns a string containing a description of the exception. You can display this description in a **println( )** statement by simply passing the exception as an argument. For example, the **catch** block in the preceding program can be rewritten like this:

```
catch (ArithmeticException e) {
  System.out.println("Exception: " + e);
  a = 0; // set a to zero and continue
}
```

When this version is substituted in the program, and the program is run, each divide-by-zero error displays the following message:

```
Exception: java.lang.ArithmeticException: / by zero
```

While it is of no particular value in this context, the ability to display a description of an exception is valuable in other circumstances—particularly when you are experimenting with exceptions or when you are debugging.

Multiple catch Clauses

In some cases, more than one exception could be raised by a single piece of code. To handle this type of situation, you can specify two or more **catch** clauses, each catching a different type of exception. When an exception is thrown, each **catch** statement is inspected in order, and the first one whose type matches that of the exception is executed. After one **catch** statement executes, the others are bypassed, and execution continues after the **try / catch** block. The following example traps two different exception types:

```
// Demonstrate multiple catch statements.
class MultipleCatches {
  public static void main(String args[]) {
    try {
      int a = args.length;
      System.out.println("a = " + a);
      int b = 42 / a;
      int c[] = { 1 };
      c[42] = 99;
    } catch(ArithmeticException e) {
      System.out.println("Divide by 0: " + e);
    } catch(ArrayIndexOutOfBoundsException e) {
      System.out.println("Array index oob: " + e);
    }
    System.out.println("After try/catch blocks.");
  }
}
```

This program will cause a division-by-zero exception if it is started with no command-line arguments, since **a** will equal zero. It will survive the division if you provide a command-line argument, setting **a** to something larger than zero. But it will cause an **ArrayIndexOutOfBoundsException**, since the **int** array **c** has a length of 1, yet the program attempts to assign a value to **c[42]**.

Here is the output generated by running it both ways:

```
C:\>java MultipleCatches
a = 0
Divide by 0: java.lang.ArithmeticException: / by zero
After try/catch blocks.

C:\>java MultipleCatches TestArg
a = 1
Array index oob: java.lang.ArrayIndexOutOfBoundsException:
Index 42 out of bounds for length 1
After try/catch blocks.
```

When you use multiple **catch** statements, it is important to remember that exception subclasses must come before any of their superclasses. This is because a **catch** statement that uses a superclass will catch exceptions of that type plus any of its subclasses. Thus, a subclass would never be reached if it came after its superclass. Further, in Java, unreachable code is an error. For example, consider the following program:

```
/* This program contains an error.

   A subclass must come before its superclass in
   a series of catch statements. If not,
   unreachable code will be created and a
   compile-time error will result.
*/
class SuperSubCatch {
  public static void main(String args[]) {
    try {
      int a = 0;
      int b = 42 / a;
     } catch(Exception e) {
       System.out.println("Generic Exception catch.");
    }
    /* This catch is never reached because
       ArithmeticException is a subclass of Exception. */
    catch(ArithmeticException e) { // ERROR - unreachable
      System.out.println("This is never reached.");
    }
  }
}
```

If you try to compile this program, you will receive an error message stating

that the second **catch** statement is unreachable because the exception has already been caught. Since **ArithmeticException** is a subclass of **Exception**, the first **catch** statement will handle all **Exception**-based errors, including **ArithmeticException**. This means that the second **catch** statement will never execute. To fix the problem, reverse the order of the **catch** statements.

Nested try Statements

The **try** statement can be nested. That is, a **try** statement can be inside the block of another **try**. Each time a **try** statement is entered, the context of that exception is pushed on the stack. If an inner **try** statement does not have a **catch** handler for a particular exception, the stack is unwound and the next **try** statement's **catch** handlers are inspected for a match. This continues until one of the **catch** statements succeeds, or until all of the nested **try** statements are exhausted. If no **catch** statement matches, then the Java run-time system will handle the exception. Here is an example that uses nested **try** statements:

```
// An example of nested try statements.
class NestTry {
  public static void main(String args[]) {
    try {
      int a = args.length;

      /* If no command-line args are present,
          the following statement will generate
          a divide-by-zero exception. */
      int b = 42 / a;

       System.out.println("a = " + a);

       try { // nested try block
         /* If one command-line arg is used,
            then a divide-by-zero exception
            will be generated by the following code. */
        if(a==1) a = a/(a-a); // division by zero

        /* If two command-line args are used,
           then generate an out-of-bounds exception. */
        if(a==2) {
           int c[] = { 1 };
           c[42] = 99; // generate an out-of-bounds exception
        }
      } catch(ArrayIndexOutOfBoundsException e) {
        System.out.println("Array index out-of-bounds: " + e);
      }

    } catch(ArithmeticException e) {
      System.out.println("Divide by 0: " + e);
    }
  }
}
```

As you can see, this program nests one **try** block within another. The program works as follows. When you execute the program with no command-line arguments, a divide-by-zero exception is generated by the outer **try** block. Execution of the program with one command-line argument generates a divide-

by-zero exception from within the nested **try** block. Since the inner block does not catch this exception, it is passed on to the outer **try** block, where it is handled. If you execute the program with two command-line arguments, an array boundary exception is generated from within the inner **try** block. Here are sample runs that illustrate each case:

```
C:\>java NestTry
Divide by 0: java.lang.ArithmeticException: / by zero

C:\>java NestTry One
a = 1
Divide by 0: java.lang.ArithmeticException: / by zero

C:\>java NestTry One Two
a = 2
Array index out-of-bounds:
  java.lang.ArrayIndexOutOfBoundsException:
  Index 42 out of bounds for length 1
```

Nesting of **try** statements can occur in less obvious ways when method calls are involved. For example, you can enclose a call to a method within a **try** block. Inside that method is another **try** statement. In this case, the **try** within the method is still nested inside the outer **try** block, which calls the method. Here is the previous program recoded so that the nested **try** block is moved inside the method **nesttry( )**:

```
/* Try statements can be implicitly nested via
   calls to methods. */
class MethNestTry {
  static void nesttry(int a) {
    try { // nested try block
      /* If one command-line arg is used,
         then a divide-by-zero exception
         will be generated by the following code. */
       if(a==1) a = a/(a-a); // division by zero

       /* If two command-line args are used,
          then generate an out-of-bounds exception. */
      if(a==2) {
        int c[] = { 1 };
        c[42] = 99; // generate an out-of-bounds exception
      }
    } catch(ArrayIndexOutOfBoundsException e) {
      System.out.println("Array index out-of-bounds: " + e);
    }
  }

  public static void main(String args[]) {
    try {
      int a = args.length;

      /* If no command-line args are present,
         the following statement will generate
         a divide-by-zero exception. */
      int b = 42 / a;
      System.out.println("a = " + a);

      nesttry(a);
    } catch(ArithmeticException e) {
      System.out.println("Divide by 0: " + e);
    }
  }
}
```

The output of this program is identical to that of the preceding example.

throw

So far, you have only been catching exceptions that are thrown by the Java run-time system. However, it is possible for your program to throw an exception explicitly, using the **throw** statement. The general form of **throw** is shown here:

throw *ThrowableInstance*;

Here, *ThrowableInstance* must be an object of type **Throwable** or a subclass of **Throwable**. Primitive types, such as **int** or **char**, as well as non-**Throwable** classes, such as **String** and **Object**, cannot be used as exceptions. There are two ways you can obtain a **Throwable** object: using a parameter in a **catch** clause or creating one with the **new** operator.

The flow of execution stops immediately after the **throw** statement; any subsequent statements are not executed. The nearest enclosing **try** block is inspected to see if it has a **catch** statement that matches the type of exception. If it does find a match, control is transferred to that statement. If not, then the next enclosing **try** statement is inspected, and so on. If no matching **catch** is found, then the default exception handler halts the program and prints the stack trace.

Here is a sample program that creates and throws an exception. The handler that catches the exception rethrows it to the outer handler.

```
// Demonstrate throw.
class ThrowDemo {
  static void demoproc() {
    try {
      throw new NullPointerException("demo");
    } catch(NullPointerException e) {
      System.out.println("Caught inside demoproc.");
      throw e; // rethrow the exception
    }
  }

  public static void main(String args[]) {
    try {
      demoproc();
    } catch(NullPointerException e) {
      System.out.println("Recaught: " + e);
    }
  }
}
```

This program gets two chances to deal with the same error. First, **main( )** sets up an exception context and then calls **demoproc( )**. The **demoproc( )** method then sets up another exception-handling context and immediately throws a new instance of **NullPointerException**, which is caught on the next line. The exception is then rethrown. Here is the resulting output:

```
Caught inside demoproc.
Recaught: java.lang.NullPointerException: demo
```

The program also illustrates how to create one of Java's standard exception objects. Pay close attention to this line:

```
throw new NullPointerException("demo");
```

Here, **new** is used to construct an instance of **NullPointerException**. Many of Java's built-in run-time exceptions have at least two constructors: one with no parameter and one that takes a string parameter. When the second form is used, the argument specifies a string that describes the exception. This string is displayed when the object is used as an argument to **print( )** or **println( )**. It can also be obtained by a call to **getMessage( )**, which is defined by **Throwable**.

throws

If a method is capable of causing an exception that it does not handle, it must specify this behavior so that callers of the method can guard themselves against that exception. You do this by including a **throws** clause in the method's declaration. A **throws** clause lists the types of exceptions that a method might throw. This is necessary for all exceptions, except those of type **Error** or **RuntimeException**, or any of their subclasses. All other exceptions that a method can throw must be declared in the **throws** clause. If they are not, a compile-time error will result.

This is the general form of a method declaration that includes a **throws** clause:

type method-name(*parameter-list*) throws *exception-list*
{
  // body of method
}

Here, *exception-list* is a comma-separated list of the exceptions that a method can throw.

Following is an example of an incorrect program that tries to throw an exception that it does not catch. Because the program does not specify a **throws** clause to declare this fact, the program will not compile.

```
// This program contains an error and will not compile.
class ThrowsDemo {
  static void throwOne() {
    System.out.println("Inside throwOne.");
    throw new IllegalAccessException("demo");
  }
  public static void main(String args[]) {
    throwOne();
  }
}
```

To make this example compile, you need to make two changes. First, you need to declare that **throwOne( )** throws **IllegalAccessException**. Second, **main( )** must define a **try / catch** statement that catches this exception.

The corrected example is shown here:

```
// This is now correct.
class ThrowsDemo {
  static void throwOne() throws IllegalAccessException {
    System.out.println("Inside throwOne.");
    throw new IllegalAccessException("demo");
  }
  public static void main(String args[]) {
    try {
      throwOne();
    } catch (IllegalAccessException e) {
      System.out.println("Caught " + e);
    }
  }
}
```

Here is the output generated by running this example program:

```
inside throwOne
caught java.lang.IllegalAccessException: demo
```

finally

When exceptions are thrown, execution in a method takes a rather abrupt, nonlinear path that alters the normal flow through the method. Depending upon how the method is coded, it is even possible for an exception to cause the method to return prematurely. This could be a problem in some methods. For example, if a method opens a file upon entry and closes it upon exit, then you will not want the code that closes the file to be bypassed by the exception-handling mechanism. The **finally** keyword is designed to address this contingency.

finally creates a block of code that will be executed after a **try /catch** block has completed and before the code following the **try/catch** block. The **finally** block will execute whether or not an exception is thrown. If an exception is thrown, the **finally** block will execute even if no **catch** statement matches the exception. Any time a method is about to return to the caller from inside a **try/catch** block, via an uncaught exception or an explicit return statement, the **finally** clause is also executed just before the method returns. This can be useful for closing file handles and freeing up any other resources that might have been

allocated at the beginning of a method with the intent of disposing of them before returning. The **finally** clause is optional. However, each **try** statement requires at least one **catch** or a **finally** clause.

Here is an example program that shows three methods that exit in various ways, none without executing their **finally** clauses:

```
// Demonstrate finally.
class FinallyDemo {
  // Throw an exception out of the method.
  static void procA() {
    try {
      System.out.println("inside procA");
      throw new RuntimeException("demo");
```

```
    } finally {
      System.out.println("procA's finally");
    }
  }

  // Return from within a try block.
  static void procB() {
    try {
      System.out.println("inside procB");
      return;
    } finally {
      System.out.println("procB's finally");
    }
  }

  // Execute a try block normally.
  static void procC() {
    try {
      System.out.println("inside procC");
    } finally {
      System.out.println("procC's finally");
    }
  }

  public static void main(String args[]) {
    try {
      procA();
    } catch (Exception e) {
      System.out.println("Exception caught");
    }

    procB();
    procC();
  }
}
```

In this example, **procA( )** prematurely breaks out of the **try** by throwing an exception. The **finally** clause is executed on the way out. **procB( )**'s **try** statement is exited via a **return** statement. The **finally** clause is executed before

procB( ) returns. In **procC( )**, the **try** statement executes normally, without error. However, the **finally** block is still executed.

REMEMBER If a **finally** block is associated with a **try**, the **finally** block will be executed upon conclusion of the **try**.

Here is the output generated by the preceding program:

```
inside procA
procA's finally
Exception caught
inside procB
procB's finally
inside procC
procC's finally
```

Java’s Built-in Exceptions

Inside the standard package **java.lang**, Java defines several exception classes. A few have been used by the preceding examples. The most general of these exceptions are subclasses of the standard type **RuntimeException**. As previously explained, these exceptions need not be included in any method’s **throws** list. In the language of Java, these are called *unchecked exceptions* because the compiler does not check to see if a method handles or throws these exceptions. The unchecked exceptions defined in **java.lang** are listed in Table 10-1. Table 10-2 lists those exceptions defined by **java.lang** that must be included in a method’s **throws** list if that method can generate one of these exceptions and does not handle it itself. These are called *checked exceptions*. In addition to the exceptions in **java .lang**, Java defines several more that relate to its other standard packages.

Exception	Meaning
ArithmeticException	Arithmetic error, such as divide-by-zero.
ArrayIndexOutOfBoundsException	Array index is out-of-bounds.
ArrayStoreException	Assignment to an array element of an incompatible type.
ClassCastException	Invalid cast.
EnumConstantNotPresentException	An attempt is made to use an undefined enumeration value.
IllegalArgumentException	Illegal argument used to invoke a method.
IllegalCallerException	A method cannot be legally executed by the calling code.
IllegalMonitorStateException	Illegal monitor operation, such as waiting on an unlocked thread.
IllegalStateException	Environment or application is in incorrect state.
IllegalThreadStateException	Requested operation not compatible with current thread state.
IndexOutOfBoundsException	Some type of index is out-of-bounds.
LayerInstantiationException	A module layer cannot be created.
NegativeArraySizeException	Array created with a negative size.
NullPointerException	Invalid use of a null reference.
NumberFormatException	Invalid conversion of a string to a numeric format.
SecurityException	Attempt to violate security.
StringIndexOutOfBoundsException	Attempt to index outside the bounds of a string.
TypeNotPresentException	Type not found.
UnsupportedOperationException	An unsupported operation was encountered.

Table 10-1 Java's Unchecked **RuntimeException** Subclasses Defined in **java.lang**

Exception	Meaning
ClassNotFoundException	Class not found.
CloneNotSupportedException	Attempt to clone an object that does not implement the **Cloneable** interface.
IllegalAccessException	Access to a class is denied.
InstantiationException	Attempt to create an object of an abstract class or interface.
InterruptedException	One thread has been interrupted by another thread.
NoSuchFieldException	A requested field does not exist.
NoSuchMethodException	A requested method does not exist.
ReflectiveOperationException	Superclass of reflection-related exceptions.

Table 10-2 Java's Checked Exceptions Defined in **java.lang**

Creating Your Own Exception Subclasses

Although Java's built-in exceptions handle most common errors, you will probably want to create your own exception types to handle situations specific to your applications. This is quite easy to do: just define a subclass of **Exception** (which is, of course, a subclass of **Throwable**). Your subclasses don't need to actually implement anything—it is their existence in the type system that allows you to use them as exceptions.

The **Exception** class does not define any methods of its own. It does, of course, inherit those methods provided by **Throwable**. Thus, all exceptions, including those that you create, have the methods defined by **Throwable** available to them. They are shown in Table 10-3. You may also wish to override one or more of these methods in exception classes that you create.

Method	Description
final void addSuppressed(Throwable *exc*)	Adds *exc* to the list of suppressed exceptions associated with the invoking exception. Primarily for use by the **try**-with-resources statement.
Throwable fillInStackTrace( )	Returns a **Throwable** object that contains a completed stack trace. This object can be rethrown.
Throwable getCause( )	Returns the exception that underlies the current exception. If there is no underlying exception, **null** is returned.
String getLocalizedMessage( )	Returns a localized description of the exception.
String getMessage( )	Returns a description of the exception.
StackTraceElement[ ] getStackTrace( )	Returns an array that contains the stack trace, one element at a time, as an array of **StackTraceElement**. The method at the top of the stack is the last method called before the exception was thrown. This method is found in the first element of the array. The **StackTraceElement** class gives your program access to information about each element in the trace, such as its method name.
final Throwable[ ] getSuppressed( )	Obtains the suppressed exceptions associated with the invoking exception and returns an array that contains the result. Suppressed exceptions are primarily generated by the **try**-with-resources statement.
Throwable initCause(Throwable *causeExc*)	Associates *causeExc* with the invoking exception as a cause of the invoking exception. Returns a reference to 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.
void setStackTrace(StackTraceElement *elements*[ ])	Sets the stack trace to the elements passed in *elements*. This method is for specialized applications, not normal use.
String toString( )	Returns a **String** object containing a description of the exception. This method is called by **println( )** when outputting a **Throwable** object.

Table 10-3 The Methods Defined by **Throwable**

Exception defines four public constructors. Two support chained exceptions,

described in the next section. The other two are shown here:

Exception( )
Exception(String *msg*)

The first form creates an exception that has no description. The second form lets you specify a description of the exception.

Although specifying a description when an exception is created is often useful, sometimes it is better to override **toString( )**. Here's why: The version of **toString( )** defined by **Throwable** (and inherited by **Exception**) first displays the name of the exception followed by a colon, which is then followed by your description. By overriding **toString( )**, you can prevent the exception name and colon from being displayed. This makes for a cleaner output, which is desirable in some cases.

The following example declares a new subclass of **Exception** and then uses that subclass to signal an error condition in a method. It overrides the **toString( )** method, allowing a carefully tailored description of the exception to be displayed.

```
// This program creates a custom exception type.
class MyException extends Exception {
  private int detail;

  MyException(int a) {
    detail = a;
  }

  public String toString() {
    return "MyException[" + detail + "]";
  }
}

class ExceptionDemo {
  static void compute(int a) throws MyException {
    System.out.println("Called compute(" + a + ")");
    if(a > 10)
      throw new MyException(a);
    System.out.println("Normal exit");
  }

  public static void main(String args[]) {
    try {
      compute(1);
      compute(20);
    } catch (MyException e) {
      System.out.println("Caught " + e);
    }
  }
}
```

This example defines a subclass of **Exception** called **MyException**. This subclass is quite simple: It has only a constructor plus an overridden **toString( )** method that displays the value of the exception. The **ExceptionDemo** class defines a method named **compute( )** that throws a **MyException** object. The exception is thrown when **compute( )**'s integer parameter is greater than 10. The **main( )** method sets up an exception handler for **MyException**, then calls **compute( )** with a legal value (less than 10) and an illegal one to show both paths through the code. Here is the result:

```
Called compute(1)
Normal exit
Called compute(20)
Caught MyException[20]
```

Chained Exceptions

A number of years ago, a feature was incorporated into the exception subsystem: *chained exceptions*. The chained exception feature allows you to associate another exception with an exception. This second exception describes the cause of the first exception. For example, imagine a situation in which a method throws an **ArithmeticException** because of an attempt to divide by zero. However, the actual cause of the problem was that an I/O error occurred, which caused the divisor to be set improperly. Although the method must certainly throw an **ArithmeticException**, since that is the error that occurred, you might also want to let the calling code know that the underlying cause was an I/O error. Chained exceptions let you handle this, and any other situation in which layers of exceptions exist.

To allow chained exceptions, two constructors and two methods were added to **Throwable**. The constructors are shown here:

Throwable(Throwable *causeExc*)
Throwable(String *msg*, Throwable *causeExc*)

In the first form, *causeExc* is the exception that causes the current exception. That is, *causeExc* is the underlying reason that an exception occurred. The second form allows you to specify a description at the same time that you specify a cause exception. These two constructors have also been added to the **Error**, **Exception**, and **RuntimeException** classes.

The chained exception methods supported by **Throwable** are **getCause( )** and **initCause( )**. These methods are shown in Table 10-3 and are repeated here for the sake of discussion.

Throwable getCause( )
Throwable initCause(Throwable *causeExc*)

The **getCause( )** method returns the exception that underlies the current exception. If there is no underlying exception, **null** is returned. The **initCause( )** method associates *causeExc* with the invoking exception and returns a reference

to the exception. Thus, you can associate a cause with an exception after the exception has been created. However, the cause exception can be set only once. This means that you can call **initCause( )** only once for each exception object. Furthermore, if the cause exception was set by a constructor, then you can't set it again using **initCause( )**. In general, **initCause( )** is used to set a cause for legacy exception classes that don't support the two additional constructors described earlier.

Here is an example that illustrates the mechanics of handling chained exceptions:

```
// Demonstrate exception chaining.
class ChainExcDemo {
  static void demoproc() {

    // create an exception
    NullPointerException e =
      new NullPointerException("top layer");

    // add a cause
    e.initCause(new ArithmeticException("cause"));

    throw e;
  }

  public static void main(String args[]) {
    try {
      demoproc();
    } catch(NullPointerException e) {
      // display top level exception
      System.out.println("Caught: " + e);

      // display cause exception
      System.out.println("Original cause: " +
                         e.getCause());
    }
  }
}
```

The output from the program is shown here:

```
Caught: java.lang.NullPointerException: top layer
Original cause: java.lang.ArithmeticException: cause
```

In this example, the top-level exception is **NullPointerException**. To it is added a cause exception, **ArithmeticException**. When the exception is thrown out of **demoproc( )**, it is caught by **main( )**. There, the top-level exception is displayed, followed by the underlying exception, which is obtained by calling **getCause( )**.

Chained exceptions can be carried on to whatever depth is necessary. Thus, the cause exception can, itself, have a cause. Be aware that overly long chains of exceptions may indicate poor design.

Chained exceptions are not something that every program will need. However, in cases in which knowledge of an underlying cause is useful, they offer an elegant solution.

Three Additional Exception Features

Beginning with JDK 7, three interesting and useful features have been part of the exception system. The first automates the process of releasing a resource, such as a file, when it is no longer needed. It is based on an expanded form of the **try** statement called ***try****-with-resources*, and is described in Chapter 13 when files are introduced. The second feature is called *multi-catch*, and the third is sometimes referred to as *final rethrow* or *more precise rethrow*. These two features are described here.

The multi-catch feature allows two or more exceptions to be caught by the same **catch** clause. It is not uncommon for two or more exception handlers to use the same code sequence even though they respond to different exceptions. Instead of having to catch each exception type individually, you can use a single **catch** clause to handle all of the exceptions without code duplication.

To use a multi-catch, separate each exception type in the **catch** clause with the OR operator. Each multi-catch parameter is implicitly **final**. (You can explicitly specify **final**, if desired, but it is not necessary.) Because each multi-catch parameter is implicitly **final**, it can’t be assigned a new value.

Here is a **catch** statement that uses the multi-catch feature to catch both **ArithmeticException** and **ArrayIndexOutOfBoundsException**:

```
catch(ArithmeticException | ArrayIndexOutOfBoundsException e) {
```

The following program shows the multi-catch feature in action:

```
// Demonstrate the multi-catch feature.
class MultiCatch {
  public static void main(String args[]) {
    int a=10, b=0;
    int vals[] = { 1, 2, 3 };

    try {
      int result = a / b; // generate an ArithmeticException

//      vals[10] = 19; // generate an ArrayIndexOutOfBoundsException

      // This catch clause catches both exceptions.
    } catch(ArithmeticException | ArrayIndexOutOfBoundsException e) {
      System.out.println("Exception caught: " + e);
    }

    System.out.println("After multi-catch.");
  }
}
```

The program will generate an **ArithmeticException** when the division by zero is attempted. If you comment out the division statement and remove the comment symbol from the next line, an **ArrayIndexOutOfBoundsException** is generated. Both exceptions are caught by the single **catch** statement.

The more precise rethrow feature restricts the type of exceptions that can be rethrown to only those checked exceptions that the associated **try** block throws, that are not handled by a preceding **catch** clause, and that are a subtype or supertype of the parameter. Although this capability might not be needed often, it is now available for use. For the more precise rethrow feature to be in force, the **catch** parameter must be either effectively **final**, which means that it must not be assigned a new value inside the **catch** block, or explicitly declared **final**.

Using Exceptions

Exception handling provides a powerful mechanism for controlling complex programs that have many dynamic run-time characteristics. It is important to think of **try**, **throw**, and **catch** as clean ways to handle errors and unusual boundary conditions in your program's logic. Instead of using error return codes to indicate failure, use Java's exception handling capabilities. Thus, when a method can fail, have it throw an exception. This is a cleaner way to handle

failure modes.

One last point: Java’s exception-handling statements should not be considered a general mechanism for nonlocal branching. If you do so, it will only confuse your code and make it hard to maintain.

CHAPTER

11

Multithreaded Programming

Java provides built-in support for *multithreaded programming*. A multithreaded program contains two or more parts that can run concurrently. Each part of such a program is called a *thread*, and each thread defines a separate path of execution. Thus, multithreading is a specialized form of multitasking.

You are almost certainly acquainted with multitasking because it is supported by virtually all modern operating systems. However, there are two distinct types of multitasking: process-based and thread-based. It is important to understand the difference between the two. For many readers, process-based multitasking is the more familiar form. A *process* is, in essence, a program that is executing. Thus, *process-based* multitasking is the feature that allows your computer to run two or more programs concurrently. For example, process-based multitasking enables you to run the Java compiler at the same time that you are using a text editor or visiting a web site. In process-based multitasking, a program is the smallest unit of code that can be dispatched by the scheduler.

In a *thread-based* multitasking environment, the thread is the smallest unit of dispatchable code. This means that a single program can perform two or more tasks simultaneously. For instance, a text editor can format text at the same time that it is printing, as long as these two actions are being performed by two separate threads. Thus, process-based multitasking deals with the “big picture,” and thread-based multitasking handles the details.

Multitasking threads require less overhead than multitasking processes. Processes are heavyweight tasks that require their own separate address spaces. Interprocess communication is expensive and limited. Context switching from one process to another is also costly. Threads, on the other hand, are lighter weight. They share the same address space and cooperatively share the same heavyweight process. Interthread communication is inexpensive, and context switching from one thread to the next is lower in cost. While Java programs make use of process-based multitasking environments, process-based multitasking is not under Java’s direct control. However, multithreaded multitasking is.

Multithreading enables you to write efficient programs that make maximum use of the processing power available in the system. One important way

multithreading achieves this is by keeping idle time to a minimum. This is especially important for the interactive, networked environment in which Java operates because idle time is common. For example, the transmission rate of data over a network is much slower than the rate at which the computer can process it. Even local file system resources are read and written at a much slower pace than they can be processed by the CPU. And, of course, user input is much slower than the computer. In a single-threaded environment, your program has to wait for each of these tasks to finish before it can proceed to the next one—even though most of the time the program is idle, waiting for input. Multithreading helps you reduce this idle time because another thread can run when one is waiting.

If you have programmed for operating systems such as Windows, then you are already familiar with multithreaded programming. However, the fact that Java manages threads makes multithreading especially convenient because many of the details are handled for you.

The Java Thread Model

The Java run-time system depends on threads for many things, and all the class libraries are designed with multithreading in mind. In fact, Java uses threads to enable the entire environment to be asynchronous. This helps reduce inefficiency by preventing the waste of CPU cycles.

The value of a multithreaded environment is best understood in contrast to its counterpart. Single-threaded systems use an approach called an *event loop* with *polling*. In this model, a single thread of control runs in an infinite loop, polling a single event queue to decide what to do next. Once this polling mechanism returns with, say, a signal that a network file is ready to be read, then the event loop dispatches control to the appropriate event handler. Until this event handler returns, nothing else can happen in the program. This wastes CPU time. It can also result in one part of a program dominating the system and preventing any other events from being processed. In general, in a single-threaded environment, when a thread *blocks* (that is, suspends execution) because it is waiting for some resource, the entire program stops running.

The benefit of Java's multithreading is that the main loop/polling mechanism is eliminated. One thread can pause without stopping other parts of your program. For example, the idle time created when a thread reads data from a network or waits for user input can be utilized elsewhere. Multithreading allows animation loops to sleep for a second between each frame without causing the

whole system to pause. When a thread blocks in a Java program, only the single thread that is blocked pauses. All other threads continue to run.

As most readers know, over the past few years, multicore systems have become commonplace. Of course, single-core systems are still in widespread use. It is important to understand that Java's multithreading features work in both types of systems. In a single-core system, concurrently executing threads share the CPU, with each thread receiving a slice of CPU time. Therefore, in a single-core system, two or more threads do not actually run at the same time, but idle CPU time is utilized. However, in multicore systems, it is possible for two or more threads to actually execute simultaneously. In many cases, this can further improve program efficiency and increase the speed of certain operations.

NOTE In addition to the multithreading features described in this chapter, you will also want to explore the Fork/Join Framework. It provides a powerful means of creating multithreaded applications that automatically scale to make best use of multicore environments. The Fork/Join Framework is part of Java's support for *parallel programming*, which is the name commonly given to the techniques that optimize some types of algorithms for parallel execution in systems that have more than one CPU. For a discussion of the Fork/Join Framework and other concurrency utilities, see Chapter 28. Java's traditional multithreading capabilities are described here.

Threads exist in several states. Here is a general description. A thread can be *running*. It can be *ready to run* as soon as it gets CPU time. A running thread can be *suspended*, which temporarily halts its activity. A suspended thread can then be *resumed*, allowing it to pick up where it left off. A thread can be *blocked* when waiting for a resource. At any time, a thread can be terminated, which halts its execution immediately. Once terminated, a thread cannot be resumed.

Thread Priorities

Java assigns to each thread a priority that determines how that thread should be treated with respect to the others. Thread priorities are integers that specify the relative priority of one thread to another. As an absolute value, a priority is meaningless; a higher-priority thread doesn't run any faster than a lower-priority thread if it is the only thread running. Instead, a thread's priority is used to decide when to switch from one running thread to the next. This is called a *context switch*. The rules that determine when a context switch takes place are simple:

- *A thread can voluntarily relinquish control*. This occurs when explicitly yielding, sleeping, or when blocked. In this scenario, all other threads are examined, and the highest-priority thread that is ready to run is given the

CPU.

- *A thread can be preempted by a higher-priority thread*. In this case, a lower-priority thread that does not yield the processor is simply preempted —no matter what it is doing—by a higher-priority thread. Basically, as soon as a higher-priority thread wants to run, it does. This is called *preemptive multitasking*.

In cases where two threads with the same priority are competing for CPU cycles, the situation is a bit complicated. For some operating systems, threads of equal priority are time-sliced automatically in round-robin fashion. For other types of operating systems, threads of equal priority must voluntarily yield control to their peers. If they don't, the other threads will not run.

CAUTION Portability problems can arise from the differences in the way that operating systems context-switch threads of equal priority.

Synchronization

Because multithreading introduces an asynchronous behavior to your programs, there must be a way for you to enforce synchronicity when you need it. For example, if you want two threads to communicate and share a complicated data structure, such as a linked list, you need some way to ensure that they don't conflict with each other. That is, you must prevent one thread from writing data while another thread is in the middle of reading it. For this purpose, Java implements an elegant twist on an age-old model of interprocess synchronization: the *monitor*. The monitor is a control mechanism first defined by C.A.R. Hoare. You can think of a monitor as a very small box that can hold only one thread. Once a thread enters a monitor, all other threads must wait until that thread exits the monitor. In this way, a monitor can be used to protect a shared asset from being manipulated by more than one thread at a time.

In Java, there is no class "Monitor"; instead, each object has its own implicit monitor that is automatically entered when one of the object's synchronized methods is called. Once a thread is inside a synchronized method, no other thread can call any other synchronized method on the same object. This enables you to write very clear and concise multithreaded code, because synchronization support is built into the language.

Messaging

After you divide your program into separate threads, you need to define how they will communicate with each other. When programming with some other languages, you must depend on the operating system to establish communication between threads. This, of course, adds overhead. By contrast, Java provides a clean, low-cost way for two or more threads to talk to each other, via calls to predefined methods that all objects have. Java's messaging system allows a thread to enter a synchronized method on an object, and then wait there until some other thread explicitly notifies it to come out.

The Thread Class and the Runnable Interface

Java's multithreading system is built upon the **Thread** class, its methods, and its companion interface, **Runnable**. **Thread** encapsulates a thread of execution. Since you can't directly refer to the ethereal state of a running thread, you will deal with it through its proxy, the **Thread** instance that spawned it. To create a new thread, your program will either extend **Thread** or implement the **Runnable** interface.

The **Thread** class defines several methods that help manage threads. Several of those used in this chapter are shown here:

Method	Meaning
getName	Obtain a thread's name.
getPriority	Obtain a thread's priority.
isAlive	Determine if a thread is still running.
join	Wait for a thread to terminate.
run	Entry point for the thread.
sleep	Suspend a thread for a period of time.
start	Start a thread by calling its run method.

Thus far, all the examples in this book have used a single thread of execution. The remainder of this chapter explains how to use **Thread** and **Runnable** to create and manage threads, beginning with the one thread that all Java programs have: the main thread.

The Main Thread

When a Java program starts up, one thread begins running immediately. This is

usually called the *main thread* of your program, because it is the one that is executed when your program begins. The main thread is important for two reasons:

- It is the thread from which other "child" threads will be spawned.
- Often, it must be the last thread to finish execution because it performs various shutdown actions.

Although the main thread is created automatically when your program is started, it can be controlled through a **Thread** object. To do so, you must obtain a reference to it by calling the method **currentThread( )**, which is a **public static** member of **Thread**. Its general form is shown here:

static Thread currentThread( )

This method returns a reference to the thread in which it is called. Once you have a reference to the main thread, you can control it just like any other thread.

Let's begin by reviewing the following example:

```
// Controlling the main Thread.
class CurrentThreadDemo {
  public static void main(String args[]) {
    Thread t = Thread.currentThread();

    System.out.println("Current thread: " + t);

    // change the name of the thread
    t.setName("My Thread");
    System.out.println("After name change: " + t);

    try {
      for(int n = 5; n > 0; n--) {
        System.out.println(n);
        Thread.sleep(1000);
      }
    } catch (InterruptedException e) {
      System.out.println("Main thread interrupted");
    }
  }
}
```

In this program, a reference to the current thread (the main thread, in this case) is obtained by calling **currentThread( )**, and this reference is stored in the local variable **t**. Next, the program displays information about the thread. The program then calls **setName( )** to change the internal name of the thread. Information about the thread is then redisplayed. Next, a loop counts down from five, pausing one second between each line. The pause is accomplished by the **sleep( )** method. The argument to **sleep( )** specifies the delay period in milliseconds. Notice the **try/catch** block around this loop. The **sleep( )** method in **Thread** might throw an **InterruptedException**. This would happen if some other thread wanted to interrupt this sleeping one. This example just prints a message if it gets interrupted. In a real program, you would need to handle this differently. Here is the output generated by this program:

```
Current thread: Thread[main,5,main]
After name change: Thread[My Thread,5,main]
5
4
3
2
1
```

Notice the output produced when **t** is used as an argument to **println( )**. This displays, in order: the name of the thread, its priority, and the name of its group. By default, the name of the main thread is **main**. Its priority is 5, which is the default value, and **main** is also the name of the group of threads to which this thread belongs. A *thread group* is a data structure that controls the state of a collection of threads as a whole. After the name of the thread is changed, **t** is again output. This time, the new name of the thread is displayed.

Let’s look more closely at the methods defined by **Thread** that are used in the program. The **sleep( )** method causes the thread from which it is called to suspend execution for the specified period of milliseconds. Its general form is shown here:

static void sleep(long *milliseconds*) throws InterruptedException

The number of milliseconds to suspend is specified in *milliseconds*. This method may throw an **InterruptedException**.

The **sleep( )** method has a second form, shown next, which allows you to specify the period in terms of milliseconds and nanoseconds:

static void sleep(long *milliseconds*, int *nanoseconds*) throws

InterruptedException

This second form is useful only in environments that allow timing periods as short as nanoseconds.

As the preceding program shows, you can set the name of a thread by using **setName( )**. You can obtain the name of a thread by calling **getName( )** (but note that this is not shown in the program). These methods are members of the **Thread** class and are declared like this:

final void setName(String *threadName*)
final String getName( )

Here, *threadName* specifies the name of the thread.

Creating a Thread

In the most general sense, you create a thread by instantiating an object of type **Thread**. Java defines two ways in which this can be accomplished:

- You can implement the **Runnable** interface.
- You can extend the **Thread** class, itself.

The following two sections look at each method, in turn.

Implementing Runnable

The easiest way to create a thread is to create a class that implements the **Runnable** interface. **Runnable** abstracts a unit of executable code. You can construct a thread on any object that implements **Runnable**. To implement **Runnable**, a class need only implement a single method called **run( )**, which is declared like this:

public void run( )

Inside **run( )**, you will define the code that constitutes the new thread. It is important to understand that **run( )** can call other methods, use other classes, and declare variables, just like the main thread can. The only difference is that **run( )** establishes the entry point for another, concurrent thread of execution within your program. This thread will end when **run( )** returns.

After you create a class that implements **Runnable**, you will instantiate an object of type **Thread** from within that class. **Thread** defines several constructors. The one that we will use is shown here:

Thread(Runnable *threadOb*, String *threadName*)

In this constructor, *threadOb* is an instance of a class that implements the **Runnable** interface. This defines where execution of the thread will begin. The name of the new thread is specified by *threadName*.

After the new thread is created, it will not start running until you call its **start( )** method, which is declared within **Thread**. In essence, **start( )** initiates a call to **run( )**. The **start( )** method is shown here:

void start( )

Here is an example that creates a new thread and starts it running:

```
// Create a second thread.
class NewThread implements Runnable {
  Thread t;

  NewThread() {
    // Create a new, second thread
    t = new Thread(this, "Demo Thread");
    System.out.println("Child thread: " + t);
  }

  // This is the entry point for the second thread.
  public void run() {
    try {
      for(int i = 5; i > 0; i--) {
        System.out.println("Child Thread: " + i);
        Thread.sleep(500);
      }
    } catch (InterruptedException e) {
      System.out.println("Child interrupted.");
    }
    System.out.println("Exiting child thread.");
  }
}
```

```
class ThreadDemo {
  public static void main(String args[]) {
    NewThread nt = new NewThread(); // create a new thread

    nt.t.start(); // Start the thread

    try {
      for(int i = 5; i > 0; i--) {
        System.out.println("Main Thread: " + i);
        Thread.sleep(1000);
      }
    } catch (InterruptedException e) {
      System.out.println("Main thread interrupted.");
    }
    System.out.println("Main thread exiting.");
  }
}
```

Inside **NewThread**'s constructor, a new **Thread** object is created by the following statement:

```
t = new Thread(this, "Demo Thread");
```

Passing **this** as the first argument indicates that you want the new thread to call the **run( )** method on **this** object. Inside **main( )**, **start( )** is called, which starts the thread of execution beginning at the **run( )** method. This causes the child thread's **for** loop to begin. Next the main thread enters its **for** loop. Both threads continue running, sharing the CPU in single-core systems, until their loops finish. The output produced by this program is as follows.(Your output may vary based upon the specific execution environment.)

```
Child thread: Thread[Demo Thread,5,main]
Main Thread: 5
Child Thread: 5
Child Thread: 4
Main Thread: 4
Child Thread: 3
Child Thread: 2
Main Thread: 3
Child Thread: 1
Exiting child thread.
```

```
Main Thread: 2
Main Thread: 1
Main thread exiting.
```

As mentioned earlier, in a multithreaded program, it is often useful for the main thread to be the last thread to finish running. The preceding program ensures that the main thread finishes last, because the main thread sleeps for 1,000 milliseconds between iterations, but the child thread sleeps for only 500 milliseconds. This causes the child thread to terminate earlier than the main thread. Shortly, you will see a better way to wait for a thread to finish.

Extending Thread

The second way to create a thread is to create a new class that extends **Thread**, and then to create an instance of that class. The extending class must override the **run( )** method, which is the entry point for the new thread. As before, a call to **start( )** begins execution of the new thread. Here is the preceding program rewritten to extend **Thread**:

```
// Create a second thread by extending Thread
class NewThread extends Thread {

  NewThread() {
    // Create a new, second thread
    super("Demo Thread");
    System.out.println("Child thread: " + this);
  }

  // This is the entry point for the second thread.
  public void run() {
    try {
      for(int i = 5; i > 0; i--) {
        System.out.println("Child Thread: " + i);
        Thread.sleep(500);
      }
    } catch (InterruptedException e) {
      System.out.println("Child interrupted.");
    }
    System.out.println("Exiting child thread.");
  }
}

class ExtendThread {
  public static void main(String args[]) {
    NewThread nt = new NewThread(); // create a new thread

    nt.start(); // start the thread

    try {
      for(int i = 5; i > 0; i--) {
        System.out.println("Main Thread: " + i);
        Thread.sleep(1000);
      }
    } catch (InterruptedException e) {
      System.out.println("Main thread interrupted.");
    }
    System.out.println("Main thread exiting.");
  }
}
```

This program generates the same output as the preceding version. As you can see, the child thread is created by instantiating an object of **NewThread**, which is derived from **Thread**.

Notice the call to **super( )** inside **NewThread**. This invokes the following form of the **Thread** constructor:

public Thread(String *threadName*)

Here, *threadName* specifies the name of the thread.

Choosing an Approach

At this point, you might be wondering why Java has two ways to create child threads, and which approach is better. The answers to these questions turn on the same point. The **Thread** class defines several methods that can be overridden by a derived class. Of these methods, the only one that *must* be overridden is **run( )**. This is, of course, the same method required when you implement **Runnable**. Many Java programmers feel that classes should be extended only when they are being enhanced or adapted in some way. So, if you will not be overriding any of **Thread**'s other methods, it is probably best simply to implement **Runnable**. Also, by implementing **Runnable**, your thread class does not need to inherit **Thread**, making it free to inherit a different class. Ultimately, which approach to use is up to you. However, throughout the rest of this chapter, we will create threads by using classes that implement **Runnable**.

Creating Multiple Threads

So far, you have been using only two threads: the main thread and one child thread. However, your program can spawn as many threads as it needs. For example, the following program creates three child threads:

```
// Create multiple threads.
class NewThread implements Runnable {
  String name; // name of thread
  Thread t;

  NewThread(String threadname) {
    name = threadname;
    t = new Thread(this, name);
    System.out.println("New thread: " + t);
  }

  // This is the entry point for thread.
  public void run() {
    try {
      for(int i = 5; i > 0; i--) {
        System.out.println(name + ": " + i);
        Thread.sleep(1000);
      }
    } catch (InterruptedException e) {
      System.out.println(name + "Interrupted");
    }
    System.out.println(name + " exiting.");
  }
}
```

```
class MultiThreadDemo {
  public static void main(String args[]) {
    NewThread nt1 = new NewThread("One");
    NewThread nt2 = new NewThread("Two");
    NewThread nt3 = new NewThread("Three");

    // Start the threads.
    nt1.t.start();
    nt2.t.start();
    nt3.t.start();

    try {
      // wait for other threads to end
      Thread.sleep(10000);
    } catch (InterruptedException e) {
      System.out.println("Main thread Interrupted");
    }

    System.out.println("Main thread exiting.");
  }
}
```

Sample output from this program is shown here. (Your output may vary based upon the specific execution environment.)

```
New thread: Thread[One,5,main]
New thread: Thread[Two,5,main]
New thread: Thread[Three,5,main]
One: 5
Two: 5
Three: 5
One: 4
Two: 4
Three: 4
One: 3
Three: 3
Two: 3
One: 2
Three: 2
Two: 2
One: 1
Three: 1
Two: 1
```

```
One exiting.
Two exiting.
Three exiting.
Main thread exiting.
```

As you can see, once started, all three child threads share the CPU. Notice the call to **sleep(10000)** in **main( )**. This causes the main thread to sleep for ten seconds and ensures that it will finish last.

Using isAlive( ) and join( )

As mentioned, often you will want the main thread to finish last. In the preceding examples, this is accomplished by calling **sleep( )** within **main( )**, with a long enough delay to ensure that all child threads terminate prior to the main thread. However, this is hardly a satisfactory solution, and it also raises a larger question: How can one thread know when another thread has ended? Fortunately, **Thread** provides a means by which you can answer this question.

Two ways exist to determine whether a thread has finished. First, you can call **isAlive( )** on the thread. This method is defined by **Thread**, and its general form is shown here:

final boolean isAlive( )

The **isAlive( )** method returns **true** if the thread upon which it is called is still running. It returns **false** otherwise.

While **isAlive( )** is occasionally useful, the method that you will more commonly use to wait for a thread to finish is called **join( )**, shown here:

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 an improved version of the preceding example that uses **join( )** to ensure that the main thread is the last to stop. It also demonstrates the **isAlive( )** method.

```
// Using join() to wait for threads to finish.
class NewThread implements Runnable {
  String name; // name of thread
  Thread t;

  NewThread(String threadname) {
    name = threadname;
    t = new Thread(this, name);
    System.out.println("New thread: " + t);
  }

  // This is the entry point for thread.
  public void run() {
    try {
      for(int i = 5; i > 0; i--) {
        System.out.println(name + ": " + i);
        Thread.sleep(1000);
      }
    } catch (InterruptedException e) {
      System.out.println(name + " interrupted.");
    }
    System.out.println(name + " exiting.");
  }
}
```

```
class DemoJoin {
  public static void main(String args[]) {
    NewThread nt1 = new NewThread("One");
    NewThread nt2 = new NewThread("Two");
    NewThread nt3 = new NewThread("Three");

    // Start the threads.
    nt1.t.start();
    nt2.t.start();
    nt3.t.start();

    System.out.println("Thread One is alive: "
                       + nt1.t.isAlive());
    System.out.println("Thread Two is alive: "
                       + nt2.t.isAlive());
    System.out.println("Thread Three is alive: "
                       + nt3.t.isAlive());
    // wait for threads to finish
    try {
      System.out.println("Waiting for threads to finish.");
      nt1.t.join();
      nt2.t.join();
      nt3.t.join();
    } catch (InterruptedException e) {
      System.out.println("Main thread Interrupted");
    }

    System.out.println("Thread One is alive: "
                       + nt1.t.isAlive());
    System.out.println("Thread Two is alive: "
                       + nt2.t.isAlive());
    System.out.println("Thread Three is alive: "
                       + nt3.t.isAlive());

    System.out.println("Main thread exiting.");
  }
}
```

Sample output from this program is shown here. (Your output may vary based

upon the specific execution environment.)

```
New thread: Thread[One,5,main]
New thread: Thread[Two,5,main]
New thread: Thread[Three,5,main]
Thread One is alive: true
Thread Two is alive: true
Thread Three is alive: true
Waiting for threads to finish.
One: 5
Two: 5
Three: 5
One: 4
Two: 4
Three: 4
One: 3
Two: 3
Three: 3
One: 2
Two: 2
Three: 2
One: 1
Two: 1
Three: 1
Two exiting.
Three exiting.
One exiting.
Thread One is alive: false
Thread Two is alive: false
Thread Three is alive: false
Main thread exiting.
```

As you can see, after the calls to **join( )** return, the threads have stopped executing.

Thread Priorities

Thread priorities are used by the thread scheduler to decide when each thread should be allowed to run. In theory, over a given period of time, higher-priority threads get more CPU time than lower-priority threads. In practice, the amount of CPU time that a thread gets often depends on several factors besides its priority. (For example, how an operating system implements multitasking can affect the relative availability of CPU time.) A higher-priority thread can also preempt a lower-priority one. For instance, when a lower-priority thread is running and a higher-priority thread resumes (from sleeping or waiting on I/O,

for example), it will preempt the lower-priority thread.

In theory, threads of equal priority should get equal access to the CPU. But you need to be careful. Remember, Java is designed to work in a wide range of environments. Some of those environments implement multitasking fundamentally differently than others. For safety, threads that share the same priority should yield control once in a while. This ensures that all threads have a chance to run under a nonpreemptive operating system. In practice, even in nonpreemptive environments, most threads still get a chance to run, because most threads inevitably encounter some blocking situation, such as waiting for I/O. When this happens, the blocked thread is suspended and other threads can run. But, if you want smooth multithreaded execution, you are better off not relying on this. Also, some types of tasks are CPU-intensive. Such threads dominate the CPU. For these types of threads, you want to yield control occasionally so that other threads can run.

To set a thread's priority, use the **setPriority( )** method, which is a member of **Thread**. This is its general form:

```
final void setPriority(int level)
```

Here, *level* specifies the new priority setting for the calling thread. The value of *level* must be within the range **MIN_PRIORITY** and **MAX_PRIORITY**. Currently, these values are 1 and 10, respectively. To return a thread to default priority, specify **NORM_PRIORITY**, which is currently 5. These priorities are defined as **static final** variables within **Thread**.

You can obtain the current priority setting by calling the **getPriority( )** method of **Thread**, shown here:

```
final int getPriority( )
```

Implementations of Java may have radically different behavior when it comes to scheduling. Most of the inconsistencies arise when you have threads that are relying on preemptive behavior, instead of cooperatively giving up CPU time. The safest way to obtain predictable, cross-platform behavior with Java is to use threads that voluntarily give up control of the CPU.

Synchronization

When two or more threads need access to a shared resource, they need some way

to ensure that the resource will be used by only one thread at a time. The process by which this is achieved is called *synchronization*. As you will see, Java provides unique, language-level support for it.

Key to synchronization is the concept of the monitor. A *monitor* is an object that is used as a mutually exclusive lock. Only one thread can *own* a monitor at a given time. When a thread acquires a lock, it is said to have *entered* the monitor. All other threads attempting to enter the locked monitor will be suspended until the first thread *exits* the monitor. These other threads are said to be *waiting* for the monitor. A thread that owns a monitor can reenter the same monitor if it so desires.

You can synchronize your code in either of two ways. Both involve the use of the **synchronized** keyword, and both are examined here.

Using Synchronized Methods

Synchronization is easy in Java, because all objects have their own implicit monitor associated with them. To enter an object's monitor, just call a method that has been modified with the **synchronized** keyword. While a thread is inside a synchronized method, all other threads that try to call it (or any other synchronized method) on the same instance have to wait. To exit the monitor and relinquish control of the object to the next waiting thread, the owner of the monitor simply returns from the synchronized method.

To understand the need for synchronization, let's begin with a simple example that does not use it—but should. The following program has three simple classes. The first one, **Callme**, has a single method named **call( )**. The **call( )** method takes a **String** parameter called **msg**. This method tries to print the **msg** string inside of square brackets. The interesting thing to notice is that after **call( )** prints the opening bracket and the **msg** string, it calls **Thread.sleep(1000)**, which pauses the current thread for one second.

The constructor of the next class, **Caller**, takes a reference to an instance of the **Callme** class and a **String**, which are stored in **target** and **msg**, respectively. The constructor also creates a new thread that will call this object's **run( )** method. The **run( )** method of **Caller** calls the **call( )** method on the **target** instance of **Callme**, passing in the **msg** string. Finally, the **Synch** class starts by creating a single instance of **Callme**, and three instances of **Caller**, each with a unique message string. The same instance of **Callme** is passed to each **Caller**.

```
// This program is not synchronized.
class Callme {
  void call(String msg) {
    System.out.print("[" + msg);
    try {
      Thread.sleep(1000);
    } catch(InterruptedException e) {
      System.out.println("Interrupted");
    }
    System.out.println("]");
  }
}

class Caller implements Runnable {
  String msg;
  Callme target;
  Thread t;

  public Caller(Callme targ, String s) {
    target = targ;
    msg = s;
    t = new Thread(this);
  }

  public void run() {
    target.call(msg);
  }
}

class Synch {
  public static void main(String args[]) {
    Callme target = new Callme();
    Caller ob1 = new Caller(target, "Hello");
    Caller ob2 = new Caller(target, "Synchronized");
    Caller ob3 = new Caller(target, "World");

    // Start the threads.
    ob1.t.start();
    ob2.t.start();
    ob3.t.start();

    // wait for threads to end
    try {
      ob1.t.join();
      ob2.t.join();
      ob3.t.join();
    } catch(InterruptedException e) {
      System.out.println("Interrupted");
    }
  }
}
```

Here is the output produced by this program:

```
[Hello[Synchronized[World]
]
]
```

As you can see, by calling **sleep( )**, the **call( )** method allows execution to switch to another thread. This results in the mixed-up output of the three message strings. In this program, nothing exists to stop all three threads from calling the same method, on the same object, at the same time. This is known as a *race condition*, because the three threads are racing each other to complete the method. This example used **sleep( )** to make the effects repeatable and obvious. In most situations, a race condition is more subtle and less predictable, because you can't be sure when the context switch will occur. This can cause a program to run right one time and wrong the next.

To fix the preceding program, you must *serialize* access to **call( )**. That is, you must restrict its access to only one thread at a time. To do this, you simply need to precede **call( )**'s definition with the keyword **synchronized**, as shown here:

```
class Callme {
  synchronized void call(String msg) {
  ...
```

This prevents other threads from entering **call( )** while another thread is using it. After **synchronized** has been added to **call( )**, the output of the program is as follows:

```
[Hello]
[Synchronized]
[World]
```

Any time that you have a method, or group of methods, that manipulates the internal state of an object in a multithreaded situation, you should use the **synchronized** keyword to guard the state from race conditions. Remember, once a thread enters any synchronized method on an instance, no other thread can enter any other synchronized method on the same instance. However, nonsynchronized methods on that instance will continue to be callable.

The synchronized Statement

While creating **synchronized** methods within classes that you create is an easy and effective means of achieving synchronization, it will not work in all cases. To understand why, consider the following. Imagine that you want to synchronize access to objects of a class that was not designed for multithreaded access. That is, the class does not use **synchronized** methods. Further, this class was not created by you, but by a third party, and you do not have access to the source code. Thus, you can't add **synchronized** to the appropriate methods within the class. How can access to an object of this class be synchronized? Fortunately, the solution to this problem is quite easy: You simply put calls to the methods defined by this class inside a **synchronized** block.

This is the general form of the **synchronized** statement:

```
synchronized(objRef) {
  // statements to be synchronized
}
```

Here, *objRef* is a reference to the object being synchronized. A synchronized block ensures that a call to a synchronized method that is a member of *objRef*'s class occurs only after the current thread has successfully entered *objRef*'s monitor.

Here is an alternative version of the preceding example, using a synchronized block within the **run( )** method:

```
// This program uses a synchronized block.
class Callme {
  void call(String msg) {
    System.out.print("[" + msg);
    try {
      Thread.sleep(1000);
    } catch (InterruptedException e) {
      System.out.println("Interrupted");
    }
    System.out.println("]");
  }
}

class Caller implements Runnable {
  String msg;
  Callme target;
  Thread t;

  public Caller(Callme targ, String s) {
    target = targ;
    msg = s;
    t = new Thread(this);
  }

  // synchronize calls to call()
  public void run() {
    synchronized(target) { // synchronized block
      target.call(msg);
    }
  }
}

class Synch1 {
  public static void main(String args[]) {
    Callme target = new Callme();
    Caller ob1 = new Caller(target, "Hello");
    Caller ob2 = new Caller(target, "Synchronized");
    Caller ob3 = new Caller(target, "World");
```

```
    // Start the threads.
    ob1.t.start();
    ob2.t.start();
    ob3.t.start();

    // wait for threads to end
    try {
      ob1.t.join();
      ob2.t.join();
      ob3.t.join();
    } catch(InterruptedException e) {
      System.out.println("Interrupted");
    }
  }
}
```

Here, the **call( )** method is not modified by **synchronized**. Instead, the **synchronized** statement is used inside **Caller**'s **run( )** method. This causes the same correct output as the preceding example, because each thread waits for the prior one to finish before proceeding.

Interthread Communication

The preceding examples unconditionally blocked other threads from asynchronous access to certain methods. This use of the implicit monitors in Java objects is powerful, but you can achieve a more subtle level of control through interprocess communication. As you will see, this is especially easy in Java.

As discussed earlier, multithreading replaces event loop programming by dividing your tasks into discrete, logical units. Threads also provide a secondary benefit: they do away with polling. Polling is usually implemented by a loop that is used to check some condition repeatedly. Once the condition is true, appropriate action is taken. This wastes CPU time. For example, consider the classic queuing problem, where one thread is producing some data and another is consuming it. To make the problem more interesting, suppose that the producer has to wait until the consumer is finished before it generates more data. In a polling system, the consumer would waste many CPU cycles while it waited for the producer to produce. Once the producer was finished, it would start polling,

wasting more CPU cycles waiting for the consumer to finish, and so on. Clearly, this situation is undesirable.

To avoid polling, Java includes an elegant interprocess communication mechanism via the **wait( )**, **notify( )**, and **notifyAll( )** methods. These methods are implemented as **final** methods in **Object**, so all classes have them. All three methods can be called only from within a **synchronized** context. Although conceptually advanced from a computer science perspective, the rules for using these methods are actually quite simple:

- **wait( )** tells the calling thread to give up the monitor and go to sleep until some other thread enters the same monitor and calls **notify( )** or **notifyAll( )**.
- **notify( )** wakes up a thread that called **wait( )** on the same object.
- **notifyAll( )** wakes up all the threads that called **wait( )** on the same object. One of the threads will be granted access.

These methods are declared within **Object**, as shown here:

```
final void wait( ) throws InterruptedException
final void notify( )
final void notify All( )
```

Additional forms of **wait( )** exist that allow you to specify a period of time to wait.

Before working through an example that illustrates interthread communication, an important point needs to be made. Although **wait( )** normally waits until **notify( )** or **notifyAll( )** is called, there is a possibility that in very rare cases the waiting thread could be awakened due to a *spurious wakeup*. In this case, a waiting thread resumes without **notify( )** or **notifyAll( )** having been called. (In essence, the thread resumes for no apparent reason.) Because of this remote possibility, the Java API documentation recommends that calls to **wait( )** should take place within a loop that checks the condition on which the thread is waiting. The following example shows this technique.

Let’s now work through an example that uses **wait( )** and **notify( )**. To begin, consider the following sample program that incorrectly implements a simple form of the producer/consumer problem. It consists of four classes: **Q**, the queue that you’re trying to synchronize; **Producer**, the threaded object that is producing queue entries; **Consumer**, the threaded object that is consuming queue entries; and **PC**, the tiny class that creates the single **Q**, **Producer**, and

Consumer.

```
// An incorrect implementation of a producer and consumer.
class Q {
  int n;

  synchronized int get() {
    System.out.println("Got: " + n);
    return n;
  }

  synchronized void put(int n) {
    this.n = n;
    System.out.println("Put: " + n);
  }
}

class Producer implements Runnable {
  Q q;
  Thread t;

  Producer(Q q) {
    this.q = q;
    t = new Thread(this, "Producer");
  }

  public void run() {
    int i = 0;

    while(true) {
      q.put(i++);
```

```
    }
  }
}

class Consumer implements Runnable {
  Q q;
  Thread t;

  Consumer(Q q) {
    this.q = q;
    t = new Thread(this, "Consumer");
  }

  public void run() {
    while(true) {
      q.get();
    }
  }
}

class PC {
  public static void main(String args[]) {
    Q q = new Q();
    Producer p = new Producer(q);
    Consumer c = new Consumer(q);

    // Start the threads.
    p.t.start();
    c.t.start();

    System.out.println("Press Control-C to stop.");
  }
}
```

Although the **put( )** and **get( )** methods on **Q** are synchronized, nothing stops the producer from overrunning the consumer, nor will anything stop the consumer from consuming the same queue value twice. Thus, you get the erroneous output shown here (the exact output will vary with processor speed and task load):

```
Put: 1
Got: 1
Got: 1
Got: 1
Got: 1
Got: 1
Put: 2
Put: 3
Put: 4
Put: 5
Put: 6
Put: 7
Got: 7
```

As you can see, after the producer put 1, the consumer started and got the same 1 five times in a row. Then, the producer resumed and produced 2 through 7 without letting the consumer have a chance to consume them.

The proper way to write this program in Java is to use **wait( )** and **notify( )** to signal in both directions, as shown here:

```
// A correct implementation of a producer and consumer.
class Q {
  int n;
  boolean valueSet = false;

  synchronized int get() {
    while(!valueSet)
      try {
        wait();

      } catch(InterruptedException e) {
        System.out.println("InterruptedException caught");
      }

      System.out.println("Got: " + n);
      valueSet = false;
      notify();
      return n;
  }

  synchronized void put(int n) {
    while(valueSet)
      try {
        wait();
      } catch(InterruptedException e) {
        System.out.println("InterruptedException caught");
      }

      this.n = n;
      valueSet = true;
      System.out.println("Put: " + n);
      notify();
  }
}

class Producer implements Runnable {
  Q q;
  Thread t;

  Producer(Q q) {
    this.q = q;
    t = new Thread(this, "Producer");
  }

  public void run() {
    int i = 0;
```

```
    while(true) {
      q.put(i++);
    }
  }
}

class Consumer implements Runnable {
  Q q;
  Thread t;

  Consumer(Q q) {
    this.q = q;
    t = new Thread(this, "Consumer");
  }

  public void run() {
    while(true) {
      q.get();
    }
  }
}

class PCFixed {
  public static void main(String args[]) {
    Q q = new Q();
    Producer p = new Producer(q);
    Consumer c = new Consumer(q);

    // Start the threads.
    p.t.start();
    c.t.start();

    System.out.println("Press Control-C to stop.");
  }
}
```

Inside **get( )**, **wait( )** is called. This causes its execution to suspend until **Producer** notifies you that some data is ready. When this happens, execution

inside **get( )** resumes. After the data has been obtained, **get( )** calls **notify( )**. This tells **Producer** that it is okay to put more data in the queue. Inside **put( )**, **wait( )** suspends execution until **Consumer** has removed the item from the queue. When execution resumes, the next item of data is put in the queue, and **notify( )** is called. This tells **Consumer** that it should now remove it.

Here is some output from this program, which shows the clean synchronous behavior:

```
Put: 1
Got: 1
Put: 2
Got: 2
Put: 3
Got: 3
Put: 4
Got: 4
Put: 5
Got: 5
```

Deadlock

A special type of error that you need to avoid that relates specifically to multitasking is *deadlock*, which occurs when two threads have a circular dependency on a pair of synchronized objects. For example, suppose one thread enters the monitor on object X and another thread enters the monitor on object Y. If the thread in X tries to call any synchronized method on Y, it will block as expected. However, if the thread in Y, in turn, tries to call any synchronized method on X, the thread waits forever, because to access X, it would have to release its own lock on Y so that the first thread could complete. Deadlock is a difficult error to debug for two reasons:

- In general, it occurs only rarely, when the two threads time-slice in just the right way.
- It may involve more than two threads and two synchronized objects. (That is, deadlock can occur through a more convoluted sequence of events than just described.)

To understand deadlock fully, it is useful to see it in action. The next example creates two classes, **A** and **B**, with methods **foo( )** and **bar( )**, respectively, which pause briefly before trying to call a method in the other class. The main class, named **Deadlock**, creates an **A** and a **B** instance, and then calls **deadlockStart( )** to start a second thread that sets up the deadlock condition. The **foo( )** and **bar( )**

methods use **sleep( )** as a way to force the deadlock condition to occur.

```
// An example of deadlock.
class A {
  synchronized void foo(B b) {
    String name = Thread.currentThread().getName();

    System.out.println(name + " entered A.foo");

    try {
      Thread.sleep(1000);
    } catch(Exception e) {
      System.out.println("A Interrupted");
    }

    System.out.println(name + " trying to call B.last()");
    b.last();
  }

  synchronized void last() {
    System.out.println("Inside A.last");
  }
}

class B {
  synchronized void bar(A a) {
    String name = Thread.currentThread().getName();
    System.out.println(name + " entered B.bar");

    try {
      Thread.sleep(1000);
    } catch(Exception e) {
```

```
      System.out.println("B Interrupted");
    }

    System.out.println(name + " trying to call A.last()");
    a.last();
  }

  synchronized void last() {
    System.out.println("Inside B.last");
  }
}

class Deadlock implements Runnable {
  A a = new A();
  B b = new B();
  Thread t;

  Deadlock() {
    Thread.currentThread().setName("MainThread");
    t = new Thread(this, "RacingThread");
  }

  void deadlockStart() {
    t.start();
    a.foo(b); // get lock on a in this thread.
    System.out.println("Back in main thread");
  }

  public void run() {
    b.bar(a); // get lock on b in other thread.
    System.out.println("Back in other thread");
  }

  public static void main(String args[]) {
    Deadlock dl = new Deadlock();

    dl.deadlockStart();
  }
}
```

When you run this program, you will see the output shown here, although whether **A.foo( )** or **B.bar( )** executes first will vary based on the specific execution environment.

```
MainThread entered A.foo
RacingThread entered B.bar
MainThread trying to call B.last()
RacingThread trying to call A.last()
```

Because the program has deadlocked, you need to press CTRL-C to end the program. You can see a full thread and monitor cache dump by pressing CTRL-BREAK on a PC. You will see that **RacingThread** owns the monitor on **b**, while it is waiting for the monitor on **a**. At the same time, **MainThread** owns **a** and is waiting to get **b**. This program will never complete. As this example illustrates, if your multithreaded program locks up occasionally, deadlock is one of the first conditions that you should check for.

Suspending, Resuming, and Stopping Threads

Sometimes, suspending execution of a thread is useful. For example, a separate thread can be used to display the time of day. If the user doesn't want a clock, then its thread can be suspended. Whatever the case, suspending a thread is a simple matter. Once suspended, restarting the thread is also a simple matter.

The mechanisms to suspend, stop, and resume threads differ between early versions of Java, such as Java 1.0, and more modern versions, beginning with Java 2. Prior to Java 2, a program used **suspend( )**, **resume( )**, and **stop( )**, which are methods defined by **Thread**, to pause, restart, and stop the execution of a thread. Although these methods seem to be a perfectly reasonable and convenient approach to managing the execution of threads, they must not be used for new Java programs. Here's why. The **suspend( )** method of the **Thread** class was deprecated by Java 2 several years ago. This was done because **suspend( )** can sometimes cause serious system failures. Assume that a thread has obtained locks on critical data structures. If that thread is suspended at that point, those locks are not relinquished. Other threads that may be waiting for those resources can be deadlocked.

The **resume( )** method is also deprecated. It does not cause problems, but cannot be used without the **suspend( )** method as its counterpart.

The **stop( )** method of the **Thread** class, too, was deprecated by Java 2. This was done because this method can sometimes cause serious system failures. Assume that a thread is writing to a critically important data structure and has completed only part of its changes. If that thread is stopped at that point, that data structure might be left in a corrupted state. The trouble is that **stop( )** causes any lock the calling thread holds to be released. Thus, the corrupted data might be used by another thread that is waiting on the same lock.

Because you can't now use the **suspend( )**, **resume( )**, or **stop( )** methods to control a thread, you might be thinking that no way exists to pause, restart, or terminate a thread. But, fortunately, this is not true. Instead, a thread must be designed so that the **run( )** method periodically checks to determine whether that thread should suspend, resume, or stop its own execution. Typically, this is accomplished by establishing a flag variable that indicates the execution state of the thread. As long as this flag is set to "running," the **run( )** method must continue to let the thread execute. If this variable is set to "suspend," the thread must pause. If it is set to "stop," the thread must terminate. Of course, a variety of ways exist in which to write such code, but the central theme will be the same for all programs.

The following example illustrates how the **wait( )** and **notify( )** methods that are inherited from **Object** can be used to control the execution of a thread. Let us consider its operation. The **NewThread** class contains a **boolean** instance variable named **suspendFlag**, which is used to control the execution of the thread. It is initialized to **false** by the constructor. The **run( )** method contains a **synchronized** statement block that checks **suspendFlag**. If that variable is **true**, the **wait( )** method is invoked to suspend the execution of the thread. The **mysuspend( )** method sets **suspendFlag** to **true**. The **myresume( )** method sets **suspendFlag** to **false** and invokes **notify( )** to wake up the thread. Finally, the **main( )** method has been modified to invoke the **mysuspend( )** and **myresume( )** methods.

```
// Suspending and resuming a thread the modern way.
class NewThread implements Runnable {
  String name; // name of thread
  Thread t;
```

```
  boolean suspendFlag;

  NewThread(String threadname) {
    name = threadname;
    t = new Thread(this, name);
    System.out.println("New thread: " + t);
    suspendFlag = false;
  }

  // This is the entry point for thread.
  public void run() {
    try {
      for(int i = 15; i > 0; i--) {
        System.out.println(name + ": " + i);
        Thread.sleep(200);
        synchronized(this) {
          while(suspendFlag) {
            wait();
          }
        }
      }
    } catch (InterruptedException e) {
      System.out.println(name + " interrupted.");
    }
    System.out.println(name + " exiting.");
  }

  synchronized void mysuspend() {
    suspendFlag = true;
  }

  synchronized void myresume() {
    suspendFlag = false;
    notify();
  }
}

class SuspendResume {
  public static void main(String args[]) {
    NewThread ob1 = new NewThread("One");
    NewThread ob2 = new NewThread("Two");

    ob1.t.start(); // Start the thread
    ob2.t.start(); // Start the thread

    try {
      Thread.sleep(1000);
      ob1.mysuspend();
      System.out.println("Suspending thread One");
      Thread.sleep(1000);
      ob1.myresume();
      System.out.println("Resuming thread One");
      ob2.mysuspend();
      System.out.println("Suspending thread Two");
      Thread.sleep(1000);
```

```
      ob2.myresume();
      System.out.println("Resuming thread Two");
    } catch (InterruptedException e) {
      System.out.println("Main thread Interrupted");
    }

    // wait for threads to finish
    try {
      System.out.println("Waiting for threads to finish.");
      ob1.t.join();
      ob2.t.join();
    } catch (InterruptedException e) {
      System.out.println("Main thread Interrupted");
    }

    System.out.println("Main thread exiting.");
  }
}
```

When you run the program, you will see the threads suspend and resume. Later in this book, you will see more examples that use the modern mechanism of thread control. Although this mechanism may not appear as simple to use as the old way, nevertheless, it is the way required to ensure that run-time errors don't occur. It is the approach that *must* be used for all new code.

Obtaining a Thread's State

As mentioned earlier in this chapter, a thread can exist in a number of different states. You can obtain the current state of a thread by calling the **getState( )** method defined by **Thread**. It is shown here:

```
Thread.State getState( )
```

It returns a value of type **Thread.State** that indicates the state of the thread at the time at which the call was made. **State** is an enumeration defined by **Thread**. (An enumeration is a list of named constants. It is discussed in detail in Chapter 12.) Here are the values that can be returned by **getState( )**:

Value	State
BLOCKED	A thread that has suspended execution because it is waiting to acquire a lock.
NEW	A thread that has not begun execution.
RUNNABLE	A thread that either is currently executing or will execute when it gains access to the CPU.
TERMINATED	A thread that has completed execution.
TIMED_WAITING	A thread that has suspended execution for a specified period of time, such as when it has called **sleep( )**. This state is also entered when a timeout version of **wait( )** or **join( )** is called.
WAITING	A thread that has suspended execution because it is waiting for some action to occur. For example, it is waiting because of a call to a non-timeout version of **wait( )** or **join( )**.

Figure 11-1 diagrams how the various thread states relate.

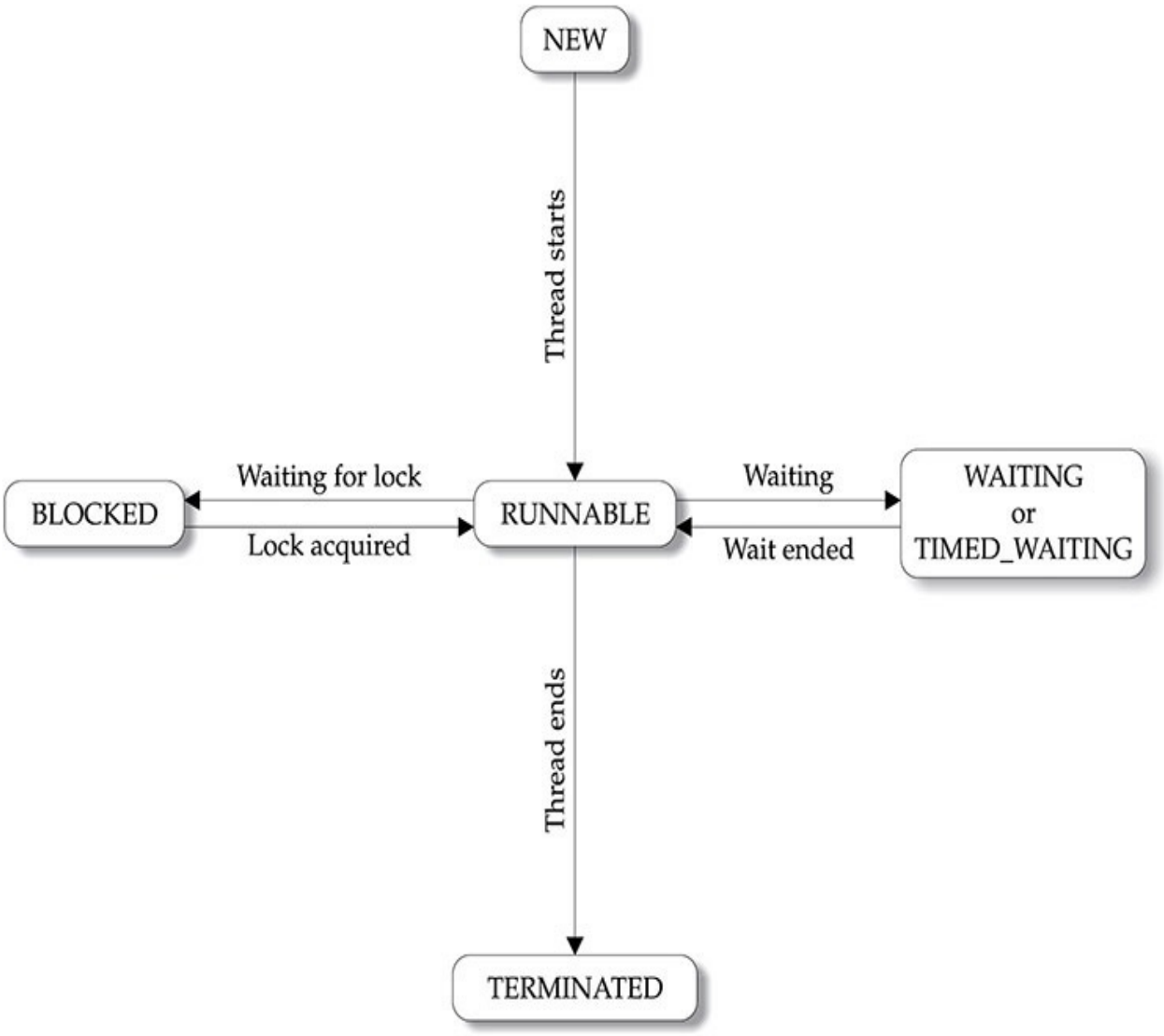


Figure 11-1 Thread states

Given a **Thread** instance, you can use **getState( )** to obtain the state of a thread. For example, the following sequence determines if a thread called **thrd** is in the **RUNNABLE** state at the time **getState( )** is called:

```
Thread.State ts = thrd.getState();

if(ts == Thread.State.RUNNABLE) // ...
```

It is important to understand that a thread's state may change after the call to **getState( )**. Thus, depending on the circumstances, the state obtained by calling **getState( )** may not reflect the actual state of the thread only a moment later. For this (and other) reasons, **getState( )** is not intended to provide a means of

synchronizing threads. It’s primarily used for debugging or for profiling a thread’s run-time characteristics.

Using a Factory Method to Create and Start a Thread

In some cases, it is not necessary to separate the creation of a thread from the start of its execution. In other words, sometimes it is convenient to create and start a thread at the same time. One way to do this is to use a static factory method. A *factory method* is a method that returns an object of a class. Typically, factory methods are *static* methods of a class. They are used for a variety of reasons, such as to set an object to some initial state prior to use, to configure a specific type of object, or in some cases to enable an object to be reused. As it relates to creating and starting a thread, a factory method will create the thread, call **start( )** on the thread, and then return a reference to the thread. With this approach, you can create and start a thread through a single method call, thus streamlining your code.

For example, assuming the **ThreadDemo** program shown near the start of this chapter, adding the following factory method to **NewThread** enables you to create and start a thread in a single step:

```
// A factory method that creates and starts a thread.
public static NewThread createAndStart() {
  NewThread myThrd = new NewThread();
  myThrd.t.start();
  return myThrd;
}
```

Using **createAndStart( )**, you can now replace this sequence:

```
NewThread nt = new NewThread(); // create a new thread
nt.t.start(); // Start the thread
```

with

```
NewThread nt = NewThread.createAndStart();
```

Now the thread is created and started in one step.

In cases in which you don’t need to keep a reference to the executing thread,

you can sometimes create and start a thread with one line of code, without the use of a factory method. For example, again assuming the **ThreadDemo** program, the following creates and starts a **NewThread** thread:

```
new NewThread().t.start();
```

However, in real-world applications, you will usually need to keep a reference to the thread, so the factory method is often a good choice.

Using Multithreading

The key to utilizing Java's multithreading features effectively is to think concurrently rather than serially. For example, when you have two subsystems within a program that can execute concurrently, make them individual threads. With the careful use of multithreading, you can create very efficient programs. A word of caution is in order, however: If you create too many threads, you can actually degrade the performance of your program rather than enhance it. Remember, some overhead is associated with context switching. If you create too many threads, more CPU time will be spent changing contexts than executing your program! One last point: To create compute-intensive applications that can automatically scale to make use of the available processors in a multicore system, consider using the Fork/Join Framework, which is described in Chapter 28.

CHAPTER

12

Enumerations, Autoboxing, and Annotations

This chapter examines three features that were not originally part of Java, but over time each has become a near indispensable aspect of Java programming: enumerations, autoboxing, and annotations. Originally added by JDK 5, each is a feature upon which Java programmers have come to rely because each offers a streamlined approach to handling common programming tasks. This chapter also discusses Java's type wrappers and introduces reflection.

Enumerations

In its simplest form, an *enumeration* is a list of named constants that define a new data type and its legal values. Thus, an enumeration object can hold only a value that was declared in the list. Other values are not allowed. In other words, an enumeration gives you a way to explicitly specify the only values that a data type can legally have. Enumerations are commonly used to define a set of values that represent a collection of items. For example, you might use an enumeration to represent the error codes that can result from some operation, such as success, failed, or pending; or a list of the states that a device might be in, such as running, stopped, or paused. In early versions of Java, such values were defined using **final** variables, but enumerations offer a far superior approach.

Although Java enumerations might, at first glance, appear similar to enumerations in other languages, this similarity may be only skin deep because, in Java, an enumeration defines a class type. By making enumerations into classes, the capabilities of the enumeration are greatly expanded. For example, in Java, an enumeration can have constructors, methods, and instance variables. Because of their power and flexibility, enumerations are widely used throughout the Java API library.

Enumeration Fundamentals

An enumeration is created using the **enum** keyword. For example, here is a

simple enumeration that lists various apple varieties:

```
// An enumeration of apple varieties.
enum Apple {
  Jonathan, GoldenDel, RedDel, Winesap, Cortland
}
```

The identifiers **Jonathan**, **GoldenDel**, and so on, are called *enumeration constants*. Each is implicitly declared as a public, static final member of **Apple**. Furthermore, their type is the type of the enumeration in which they are declared, which is **Apple** in this case. Thus, in the language of Java, these constants are called *self-typed*, in which "self" refers to the enclosing enumeration.

Once you have defined an enumeration, you can create a variable of that type. However, even though enumerations define a class type, you do not instantiate an **enum** using **new**. Instead, you declare and use an enumeration variable in much the same way as you do one of the primitive types. For example, this declares **ap** as a variable of enumeration type **Apple**:

```
Apple ap;
```

Because **ap** is of type **Apple**, the only values that it can be assigned (or can contain) are those defined by the enumeration. For example, this assigns **ap** the value **RedDel**:

```
ap = Apple.RedDel;
```

Notice that the symbol **RedDel** is preceded by **Apple**.

Two enumeration constants can be compared for equality by using the = = relational operator. For example, this statement compares the value in **ap** with the **GoldenDel** constant:

```
if(ap == Apple.GoldenDel) // ...
```

An enumeration value can also be used to control a **switch** statement. Of course, all of the **case** statements must use constants from the same **enum** as that used by the **switch** expression. For example, this **switch** is perfectly valid:

```
// Use an enum to control a switch statement.
switch(ap) {
  case Jonathan:
    // ...
  case Winesap:
    // ...
```

Notice that in the **case** statements, the names of the enumeration constants are used without being qualified by their enumeration type name. That is, **Winesap**, not **Apple.Winesap**, is used. This is because the type of the enumeration in the **switch** expression has already implicitly specified the **enum** type of the **case** constants. There is no need to qualify the constants in the **case** statements with their **enum** type name. In fact, attempting to do so will cause a compilation error.

When an enumeration constant is displayed, such as in a **println( )** statement, its name is output. For example, given this statement:

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

the name **Winesap** is displayed.

The following program puts together all of the pieces and demonstrates the **Apple** enumeration:

```
// An enumeration of apple varieties.
enum Apple {
  Jonathan, GoldenDel, RedDel, Winesap, Cortland
}

class EnumDemo {
  public static void main(String args[])
  {
    Apple ap;

    ap = Apple.RedDel;

    // Output an enum value.
    System.out.println("Value of ap: " + ap);
    System.out.println();

    ap = Apple.GoldenDel;

    // Compare two enum values.
    if(ap == Apple.GoldenDel)
      System.out.println("ap contains GoldenDel.\n");

    // Use an enum to control a switch statement.
    switch(ap) {
      case Jonathan:
        System.out.println("Jonathan is red.");
        break;
      case GoldenDel:
        System.out.println("Golden Delicious is yellow.");
        break;
      case RedDel:
        System.out.println("Red Delicious is red.");
        break;
      case Winesap:
        System.out.println("Winesap is red.");
        break;
      case Cortland:
        System.out.println("Cortland is red.");
        break;
    }
  }
}
```

The output from the program is shown here:

```
Value of ap: RedDel

ap contains GoldenDel.

Golden Delicious is yellow.
```

The values( ) and valueOf( ) Methods

All enumerations automatically contain two predefined methods: **values( )** and **valueOf( )**. Their general forms are shown here:

public static *enum-type* [ ] values( )
public static *enum-type* valueOf(String *str*)

The **values( )** method returns an array that contains a list of the enumeration constants. The **valueOf( )** method returns the enumeration constant whose value corresponds to the string passed in *str*. In both cases, *enum-type* is the type of the enumeration. For example, in the case of the **Apple** enumeration shown earlier, the return type of **Apple.valueOf("Winesap")** is **Winesap**.

The following program demonstrates the **values( )** and **valueOf( )** methods:

```
// Use the built-in enumeration methods.

// An enumeration of apple varieties.
enum Apple {
  Jonathan, GoldenDel, RedDel, Winesap, Cortland
}

class EnumDemo2 {
  public static void main(String args[])
  {
    Apple ap;

    System.out.println("Here are all Apple constants:");

    // use values()
    Apple allapples[] = Apple.values();
    for(Apple a : allapples)
      System.out.println(a);

    System.out.println();

    // use valueOf()
    ap = Apple.valueOf("Winesap");
    System.out.println("ap contains " + ap);

  }
}
```

The output from the program is shown here:

```
Here are all Apple constants:
Jonathan
GoldenDel
RedDel
Winesap
Cortland

ap contains Winesap
```

Notice that this program uses a for-each style **for** loop to cycle through the array of constants obtained by calling **values( )**. For the sake of illustration, the

variable **allapples** was created and assigned a reference to the enumeration array. However, this step is not necessary because the **for** could have been written as shown here, eliminating the need for the **allapples** variable:

```
for(Apple a : Apple.values())
  System.out.println(a);
```

Now, notice how the value corresponding to the name **Winesap** was obtained by calling **valueOf( )**.

```
ap = Apple.valueOf("Winesap");
```

As explained, **valueOf( )** returns the enumeration value associated with the name of the constant represented as a string.

Java Enumerations Are Class Types

As mentioned, a Java enumeration is a class type. Although you don't instantiate an **enum** using **new**, it otherwise has much the same capabilities as other classes. The fact that **enum** defines a class gives the Java enumeration extraordinary power. For example, you can give them constructors, add instance variables and methods, and even implement interfaces.

It is important to understand that each enumeration constant is an object of its enumeration type. Thus, when you define a constructor for an **enum**, the constructor is called when each enumeration constant is created. Also, each enumeration constant has its own copy of any instance variables defined by the enumeration. For example, consider the following version of **Apple**:

```
// Use an enum constructor, instance variable, and method.
enum Apple {
  Jonathan(10), GoldenDel(9), RedDel(12), Winesap(15), Cortland(8);

  private int price; // price of each apple

  // Constructor
  Apple(int p) { price = p; }

  int getPrice() { return price; }
}
```

```
class EnumDemo3 {
  public static void main(String args[])
  {
    Apple ap;

    // Display price of Winesap.
    System.out.println("Winesap costs " +
                       Apple.Winesap.getPrice() +
                       " cents.\n");

    // Display all apples and prices.
    System.out.println("All apple prices:");
    for(Apple a : Apple.values())
      System.out.println(a + " costs " + a.getPrice() +
                         " cents.");
  }
}
```

The output is shown here:

```
Winesap costs 15 cents.

All apple prices:
Jonathan costs 10 cents.
GoldenDel costs 9 cents.
RedDel costs 12 cents.
Winesap costs 15 cents.
Cortland costs 8 cents.
```

This version of **Apple** adds three things. The first is the instance variable **price**, which is used to hold the price of each variety of apple. The second is the **Apple** constructor, which is passed the price of an apple. The third is the method **getPrice( )**, which returns the value of **price**.

When the variable **ap** is declared in **main( )**, the constructor for **Apple** is called once for each constant that is specified. Notice how the arguments to the constructor are specified, by putting them inside parentheses after each constant, as shown here:

```
Jonathan(10), GoldenDel(9), RedDel(12), Winesap(15), Cortland(8);
```

These values are passed to the **p** parameter of **Apple( )**, which then assigns this

value to **price**. Again, the constructor is called once for each constant.

Because each enumeration constant has its own copy of **price**, you can obtain the price of a specified type of apple by calling **getPrice( )**. For example, in **main( )** the price of a Winesap is obtained by the following call:

```
Apple.Winesap.getPrice( )
```

The prices of all varieties are obtained by cycling through the enumeration using a **for** loop. Because there is a copy of **price** for each enumeration constant, the value associated with one constant is separate and distinct from the value associated with another constant. This is a powerful concept, which is only available when enumerations are implemented as classes, as Java does.

Although the preceding example contains only one constructor, an **enum** can offer two or more overloaded forms, just as can any other class. For example, this version of **Apple** provides a default constructor that initializes the price to –1, to indicate that no price data is available:

```
// Use an enum constructor.
enum Apple {
  Jonathan(10), GoldenDel(9), RedDel, Winesap(15), Cortland(8);

  private int price; // price of each apple

  // Constructor
  Apple(int p) { price = p; }

  // Overloaded constructor
  Apple() { price = -1; }

  int getPrice() { return price; }
}
```

Notice that in this version, **RedDel** is not given an argument. This means that the default constructor is called, and **RedDel**'s price variable is given the value –1.

Here are two restrictions that apply to enumerations. First, an enumeration can't inherit another class. Second, an **enum** cannot be a superclass. This means that an **enum** can't be extended. Otherwise, **enum** acts much like any other class type. The key is to remember that each of the enumeration constants is an object of the class in which it is defined.

Enumerations Inherit Enum

Although you can't inherit a superclass when declaring an **enum**, all enumerations automatically inherit one: **java.lang.Enum**. This class defines several methods that are available for use by all enumerations. The **Enum** class is described in detail in Part II, but three of its methods warrant a discussion at this time.

You can obtain a value that indicates an enumeration constant's position in the list of constants. This is called its *ordinal value,* and it is retrieved by calling the **ordinal( )** method, shown here:

final int ordinal( )

It returns the ordinal value of the invoking constant. Ordinal values begin at zero. Thus, in the **Apple** enumeration, **Jonathan** has an ordinal value of zero, **GoldenDel** has an ordinal value of 1, **RedDel** has an ordinal value of 2, and so on.

You can compare the ordinal value of two constants of the same enumeration by using the **compareTo( )** method. It has this general form:

final int compareTo(*enum-type e*)

Here, *enum-type* is the type of the enumeration, and *e* is the constant being compared to the invoking constant. Remember, both the invoking constant and *e* must be of the same enumeration. If the invoking constant has an ordinal value less than *e*'s, then **compareTo( )** returns a negative value. If the two ordinal values are the same, then zero is returned. If the invoking constant has an ordinal value greater than *e*'s, then a positive value is returned.

You can compare for equality an enumeration constant with any other object by using **equals( )**, which overrides the **equals( )** method defined by **Object**. Although **equals( )** can compare an enumeration constant to any other object, those two objects will be equal only if they both refer to the same constant, within the same enumeration. Simply having ordinal values in common will not cause **equals( )** to return true if the two constants are from different enumerations.

Remember, you can compare two enumeration references for equality by using = =.

The following program demonstrates the **ordinal( )**, **compareTo( )**, and **equals( )** methods:

```
// Demonstrate ordinal(), compareTo(), and equals().

// An enumeration of apple varieties.
enum Apple {
  Jonathan, GoldenDel, RedDel, Winesap, Cortland
}

class EnumDemo4 {
  public static void main(String args[])
  {
    Apple ap, ap2, ap3;

    // Obtain all ordinal values using ordinal().
    System.out.println("Here are all apple constants" +
                       " and their ordinal values: ");
    for(Apple a : Apple.values())
      System.out.println(a + " " + a.ordinal());

    ap =  Apple.RedDel;
    ap2 = Apple.GoldenDel;
    ap3 = Apple.RedDel;

    System.out.println();

    // Demonstrate compareTo() and equals()
    if(ap.compareTo(ap2) < 0)
      System.out.println(ap + " comes before " + ap2);

    if(ap.compareTo(ap2) > 0)
      System.out.println(ap2 + " comes before " + ap);

    if(ap.compareTo(ap3) == 0)
      System.out.println(ap + " equals " + ap3);

    System.out.println();

    if(ap.equals(ap2))
      System.out.println("Error!");

    if(ap.equals(ap3))
      System.out.println(ap + " equals " + ap3);
```

```
    if(ap == ap3)
      System.out.println(ap + " == " + ap3);

  }
}
```

The output from the program is shown here:

```
Here are all apple constants and their ordinal values:
Jonathan 0
GoldenDel 1
RedDel 2
Winesap 3
Cortland 4

GoldenDel comes before RedDel
RedDel equals RedDel

RedDel equals RedDel
RedDel == RedDel
```

Another Enumeration Example

Before moving on, we will look at a different example that uses an **enum**. In Chapter 9, an automated "decision maker" program was created. In that version, variables called **NO**, **YES**, **MAYBE**, **LATER**, **SOON**, and **NEVER** were declared within an interface and used to represent the possible answers. While there is nothing technically wrong with that approach, the enumeration is a better choice. Here is an improved version of that program that uses an **enum** called **Answers** to define the answers. You should compare this version to the original in Chapter 9.

```
// An improved version of the "Decision Maker"
// program from Chapter 9. This version uses an
// enum, rather than interface variables, to
// represent the answers.

import java.util.Random;

// An enumeration of the possible answers.
enum Answers {
  NO, YES, MAYBE, LATER, SOON, NEVER
}

class Question {
  Random rand = new Random();
  Answers ask() {
  int prob = (int) (100 * rand.nextDouble());

    if (prob < 15)
      return Answers.MAYBE; // 15%
    else if (prob < 30)
      return Answers.NO;    // 15%
    else if (prob < 60)
      return Answers.YES;   // 30%
```

```
    else if (prob < 75)
      return Answers.LATER; // 15%
    else if (prob < 98)
      return Answers.SOON;  // 13%
    else
      return Answers.NEVER; // 2%
  }
}

class AskMe {
  static void answer(Answers result) {
    switch(result) {
      case NO:
        System.out.println("No");
        break;
      case YES:
        System.out.println("Yes");
        break;
      case MAYBE:
        System.out.println("Maybe");
        break;
      case LATER:
        System.out.println("Later");
        break;
      case SOON:
        System.out.println("Soon");
        break;
      case NEVER:
        System.out.println("Never");
        break;
    }
  }

  public static void main(String args[]) {
    Question q = new Question();
    answer(q.ask());
    answer(q.ask());
    answer(q.ask());
    answer(q.ask());
  }
}
```

Type Wrappers

As you know, Java uses primitive types (also called simple types), such as **int** or **double**, to hold the basic data types supported by the language. Primitive types, rather than objects, are used for these quantities for the sake of performance. Using objects for these values would add an unacceptable overhead to even the simplest of calculations. Thus, the primitive types are not part of the object hierarchy, and they do not inherit **Object**.

Despite the performance benefit offered by the primitive types, there are times when you will need an object representation. For example, you can't pass a primitive type by reference to a method. Also, many of the standard data structures implemented by Java operate on objects, which means that you can't use these data structures to store primitive types. To handle these (and other) situations, Java provides *type wrappers*, which are classes that encapsulate a primitive type within an object. The type wrapper classes are described in detail in Part II, but they are introduced here because they relate directly to Java's autoboxing feature.

The type wrappers are **Double**, **Float**, **Long**, **Integer**, **Short**, **Byte**, **Character**, and **Boolean**. These classes offer a wide array of methods that allow you to fully integrate the primitive types into Java's object hierarchy. Each is briefly examined next.

Character

Character is a wrapper around a **char**. The constructor for **Character** is

Character(char *ch*)

Here, *ch* specifies the character that will be wrapped by the **Character** object being created.

However, beginning with JDK 9, the **Character** constructor has been deprecated. Today, it is recommended that you use the static method **valueOf( )** to obtain a **Character** object. It is shown here:

static Character valueOf(char *ch*)

It returns a **Character** object that wraps *ch*.

To obtain the **char** value contained in a **Character** object, call **charValue( )**, shown here:

char charValue( )

It returns the encapsulated character.

Boolean

Boolean is a wrapper around **boolean** values. It defines these constructors:

Boolean(boolean *boolValue*)
Boolean(String *boolString*)

In the first version, *boolValue* must be either **true** or **false**. In the second version, if *boolString* contains the string "true" (in uppercase or lowercase), then the new **Boolean** object will be true. Otherwise, it will be false.

However, beginning with JDK 9, the **Boolean** constructors have been deprecated. Today, it is recommended that you use the static method **valueOf( )** to obtain a **Boolean** object. It has the two versions shown here:

static Boolean valueOf(boolean *boolValue*)
static Boolean valueOf(String *boolString*)

Each returns a **Boolean** object that wraps the indicated value.

To obtain a **boolean** value from a **Boolean** object, use **booleanValue( )**, shown here:

boolean booleanValue( )

It returns the **boolean** equivalent of the invoking object.

The Numeric Type Wrappers

By far, the most commonly used type wrappers are those that represent numeric values. These are **Byte**, **Short**, **Integer**, **Long**, **Float**, and **Double**. All of the numeric type wrappers inherit the abstract class **Number**. **Number** declares methods that return the value of an object in each of the different number formats. These methods are shown here:

byte byteValue( )
double doubleValue( )
float floatValue( )
int intValue( )
long longValue( )
short shortValue( )

For example, **doubleValue( )** returns the value of an object as a **double**, **floatValue( )** returns the value as a **float**, and so on. These methods are implemented by each of the numeric type wrappers.

All of the numeric type wrappers define constructors that allow an object to be constructed from a given value, or a string representation of that value. For example, here are the constructors defined for **Integer**:

Integer(int *num*)
Integer(String *str*)

If *str* does not contain a valid numeric value, then a **NumberFormatException** is thrown.

However, beginning with JDK 9, the numeric type-wrapper constructors have been deprecated. Today, it is recommended that you use one of the **valueOf( )** methods to obtain a wrapper object. The **valueOf( )** method is a static member of all of the numeric wrapper classes and all numeric classes support forms that convert a numeric value or a string into an object. For example, here are two of the forms supported by **Integer**:

static Integer valueOf(int *val*)
static Integer valueOf(String *valStr*) throws NumberFormatException

Here, *val* specifies an integer value and *valStr* specifies a string that represents a properly formatted numeric value in string form. Each returns an **Integer** object that wraps the specified value. Here is an example:

```
Integer iOb = Integer.valueOf(100);
```

After this statement executes, the value 100 is represented by an **Integer** instance. Thus, **iOb** wraps the value 100 within an object. In addition to the forms **valueOf( )** just shown, the integer wrappers, **Byte**, **Short**, **Integer**, and **Long**, also supply a form that lets you specify a radix.

All of the type wrappers override **toString( )**. It returns the human-readable

form of the value contained within the wrapper. This allows you to output the value by passing a type wrapper object to **println( )**, for example, without having to convert it into its primitive type.

The following program demonstrates how to use a numeric type wrapper to encapsulate a value and then extract that value.

```
// Demonstrate a type wrapper.
class Wrap {
  public static void main(String args[]) {

    Integer iOb = Integer.valueOf(100);

    int i = iOb.intValue();

    System.out.println(i + " " + iOb); // displays 100 100
  }
}
```

This program wraps the integer value 100 inside an **Integer** object called **iOb**. The program then obtains this value by calling **intValue( )** and stores the result in **i**.

The process of encapsulating a value within an object is called *boxing*. Thus, in the program, this line boxes the value 100 into an **Integer**:

```
Integer iOb = Integer.valueOf(100);
```

The process of extracting a value from a type wrapper is called *unboxing*. For example, the program unboxes the value in **iOb** with this statement:

```
int i = iOb.intValue();
```

The same general procedure used by the preceding program to box and unbox values has been available for use since the original version of Java. However, today, Java provides a more streamlined approach, which is described next.

Autoboxing

Beginning with JDK 5, Java has included two important features: *autoboxing* and *auto-unboxing*. Autoboxing is the process by which a primitive type is

automatically encapsulated (boxed) into its equivalent type wrapper whenever an object of that type is needed. There is no need to explicitly construct an object. Auto-unboxing is the process by which the value of a boxed object is automatically extracted (unboxed) from a type wrapper when its value is needed. There is no need to call a method such as **intValue( )** or **doubleValue( )**.

Autoboxing and auto-unboxing greatly streamline the coding of several algorithms, removing the tedium of manually boxing and unboxing values. They also help prevent errors. Moreover, they are very important to generics, which operate only on objects. Finally, autoboxing makes working with the Collections Framework (described in Part II) much easier.

With autoboxing, it is not necessary to manually construct an object in order to wrap a primitive type. You need only assign that value to a type-wrapper reference. Java automatically constructs the object for you. For example, here is the modern way to construct an **Integer** object that has the value 100:

```
Integer iOb = 100; // autobox an int
```

Notice that the object is not explicitly boxed. Java handles this for you, automatically.

To unbox an object, simply assign that object reference to a primitive-type variable. For example, to unbox **iOb**, you can use this line:

```
int i = iOb; // auto-unbox
```

Java handles the details for you.

Here is the preceding program rewritten to use autoboxing/unboxing:

```
// Demonstrate autoboxing/unboxing.
class AutoBox {
  public static void main(String args[]) {

    Integer iOb = 100; // autobox an int

    int i = iOb; // auto-unbox

    System.out.println(i + " " + iOb);  // displays 100 100
  }
}
```

Autoboxing and Methods

In addition to the simple case of assignments, autoboxing automatically occurs whenever a primitive type must be converted into an object; auto-unboxing takes place whenever an object must be converted into a primitive type. Thus, autoboxing/unboxing might occur when an argument is passed to a method, or when a value is returned by a method. For example, consider this:

```
// Autoboxing/unboxing takes place with
// method parameters and return values.

class AutoBox2 {
  // Take an Integer parameter and return
  // an int value;
  static int m(Integer v) {
    return v ; // auto-unbox to int
  }

  public static void main(String args[]) {
    // Pass an int to m() and assign the return value
    // to an Integer.  Here, the argument 100 is autoboxed
    // into an Integer.  The return value is also autoboxed
    // into an Integer.
    Integer iOb = m(100);

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

This program displays the following result:

```
100
```

In the program, notice that **m( )** specifies an **Integer** parameter and returns an **int** result. Inside **main( )**, **m( )** is passed the value 100. Because **m( )** is expecting an **Integer**, this value is automatically boxed. Then, **m( )** returns the **int** equivalent of its argument. This causes **v** to be auto-unboxed. Next, this **int** value is assigned to **iOb** in **main( )**, which causes the **int** return value to be autoboxed.

Autoboxing/Unboxing Occurs in Expressions

In general, autoboxing and unboxing take place whenever a conversion into an object or from an object is required. This applies to expressions. Within an expression, a numeric object is automatically unboxed. The outcome of the expression is reboxed, if necessary. For example, consider the following program:

```
// Autoboxing/unboxing occurs inside expressions.

class AutoBox3 {
  public static void main(String args[]) {

    Integer iOb, iOb2;
    int i;

    iOb = 100;
    System.out.println("Original value of iOb: " + iOb);

    // The following automatically unboxes iOb,
    // performs the increment, and then reboxes
    // the result back into iOb.
    ++iOb;
    System.out.println("After ++iOb: " + iOb);

    // Here, iOb is unboxed, the expression is
    // evaluated, and the result is reboxed and
    // assigned to iOb2.
    iOb2 = iOb + (iOb / 3);
    System.out.println("iOb2 after expression: " + iOb2);

    // The same expression is evaluated, but the
    // result is not reboxed.
    i = iOb + (iOb / 3);
    System.out.println("i after expression: " + i);

  }
}
```

The output is shown here:

```
Original value of iOb: 100
After ++iOb: 101
iOb2 after expression: 134
i after expression: 134
```

In the program, pay special attention to this line:

```
++iOb;
```

This causes the value in **iOb** to be incremented. It works like this: **iOb** is unboxed, the value is incremented, and the result is reboxed.

Auto-unboxing also allows you to mix different types of numeric objects in an expression. Once the values are unboxed, the standard type promotions and conversions are applied. For example, the following program is perfectly valid:

```
class AutoBox4 {
  public static void main(String args[]) {

    Integer iOb = 100;
    Double dOb = 98.6;

    dOb = dOb + iOb;
    System.out.println("dOb after expression: " + dOb);
  }
}
```

The output is shown here:

```
dOb after expression: 198.6
```

As you can see, both the **Double** object **dOb** and the **Integer** object **iOb** participated in the addition, and the result was reboxed and stored in **dOb**.

Because of auto-unboxing, you can use **Integer** numeric objects to control a **switch** statement. For example, consider this fragment:

```
Integer iOb = 2;

switch(iOb) {
  case 1: System.out.println("one");
    break;
  case 2: System.out.println("two");
    break;
  default: System.out.println("error");
}
```

When the **switch** expression is evaluated, **iOb** is unboxed and its **int** value is obtained.

As the examples in the programs show, because of autoboxing/unboxing, using numeric objects in an expression is both intuitive and easy. In the past, such code would have involved casts and calls to methods such as **intValue( )**.

Autoboxing/Unboxing Boolean and Character Values

As described earlier, Java also supplies wrappers for **boolean** and **char**. These are **Boolean** and **Character**. Autoboxing/unboxing applies to these wrappers, too. For example, consider the following program:

```
// Autoboxing/unboxing a Boolean and Character.

class AutoBox5 {
  public static void main(String args[]) {
```

```
    // Autobox/unbox a boolean.
    Boolean b = true;

    // Below, b is auto-unboxed when used in
    // a conditional expression, such as an if.
    if(b) System.out.println("b is true");

    // Autobox/unbox a char.
    Character ch = 'x'; // box a char
    char ch2 = ch; // unbox a char

    System.out.println("ch2 is " + ch2);
  }
}
```

The output is shown here:

```
b is true
ch2 is x
```

The most important thing to notice about this program is the auto-unboxing of **b** inside the **if** conditional expression. As you should recall, the conditional expression that controls an **if** must evaluate to type **boolean**. Because of auto-unboxing, the **boolean** value contained within **b** is automatically unboxed when the conditional expression is evaluated. Thus, with autoboxing/unboxing, a **Boolean** object can be used to control an **if** statement.

Because of auto-unboxing, a **Boolean** object can now also be used to control any of Java's loop statements. When a **Boolean** is used as the conditional expression of a **while**, **for**, or **do/while**, it is automatically unboxed into its **boolean** equivalent. For example, this is perfectly valid code:

```
Boolean b;
// ...
while(b) { // ...
```

Autoboxing/Unboxing Helps Prevent Errors

In addition to the convenience that it offers, autoboxing/unboxing can also help prevent errors. For example, consider the following program:

```
// An error produced by manual unboxing.
class UnboxingError {
  public static void main(String args[]) {

    Integer iOb = 1000; // autobox the value 1000

    int i = iOb.byteValue(); // manually unbox as byte !!!

    System.out.println(i);  // does not display 1000 !
  }
}
```

This program displays not the expected value of 1000, but –24! The reason is that the value inside **iOb** is manually unboxed by calling **byteValue( )**, which causes the truncation of the value stored in **iOb**, which is 1,000. This results in the garbage value of –24 being assigned to **i**. Auto-unboxing prevents this type of error because the value in **iOb** will always auto-unbox into a value compatible with **int**.

In general, because autoboxing always creates the proper object, and auto-unboxing always produces the proper value, there is no way for the process to produce the wrong type of object or value. In the rare instances where you want a type different than that produced by the automated process, you can still manually box and unbox values. Of course, the benefits of autoboxing/unboxing are lost. In general, you should employ autoboxing/unboxing. It is the way that modern Java code is written.

A Word of Warning

Because of autoboxing and auto-unboxing, some might be tempted to use objects such as **Integer** or **Double** exclusively, abandoning primitives altogether. For example, with autoboxing/unboxing it is possible to write code like this:

```
// A bad use of autoboxing/unboxing!
Double a, b, c;

a = 10.0;
b = 4.0;

c = Math.sqrt(a*a + b*b);

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

In this example, objects of type **Double** hold values that are used to calculate the hypotenuse of a right triangle. Although this code is technically correct and does, in fact, work properly, it is a very bad use of autoboxing/unboxing. It is far less efficient than the equivalent code written using the primitive type **double**. The reason is that each autobox and auto-unbox adds overhead that is not present if the primitive type is used.

In general, you should restrict your use of the type wrappers to only those cases in which an object representation of a primitive type is required. Autoboxing/unboxing was not added to Java as a "back door" way of eliminating the primitive types.

Annotations

Java provides a feature that enables you to embed supplemental information into a source file. This information, called an *annotation*, does not change the actions of a program. Thus, an annotation leaves the semantics of a program unchanged. However, this information can be used by various tools during both development and deployment. For example, an annotation might be processed by a source-code generator. The term *metadata* is also used to refer to this feature, but the term *annotation* is the most descriptive and more commonly used.

Annotation Basics

An annotation is created through a mechanism based on the **interface**. Let's begin with an example. Here is the declaration for an annotation called **MyAnno**:

```
// A simple annotation type.
@interface MyAnno {
  String str();
  int val();
}
```

First, notice the @ that precedes the keyword **interface**. This tells the compiler that an annotation type is being declared. Next, notice the two members **str( )** and **val( )**. All annotations consist solely of method declarations. However, you don't provide bodies for these methods. Instead, Java implements these methods. Moreover, the methods act much like fields, as you will see.

An annotation cannot include an **extends** clause. However, all annotation types automatically extend the **Annotation** interface. Thus, **Annotation** is a super-interface of all annotations. It is declared within the **java.lang.annotation** package. It overrides **hashCode( )**, **equals( )**, and **toString( )**, which are defined by **Object**. It also specifies **annotationType( )**, which returns a **Class** object that represents the invoking annotation.

Once you have declared an annotation, you can use it to annotate something. Prior to JDK 8, annotations could be used only on declarations, and that is where we will begin. (JDK 8 added the ability to annotate type use, and this is described later in this chapter. However, the same basic techniques apply to both kinds of annotations.) Any type of declaration can have an annotation associated with it. For example, classes, methods, fields, parameters, and **enum** constants can be annotated. Even an annotation can be annotated. In all cases, the annotation precedes the rest of the declaration.

When you apply an annotation, you give values to its members. For example, here is an example of **MyAnno** being applied to a method declaration:

```
// Annotate a method.
@MyAnno(str = "Annotation Example", val = 100)
public static void myMeth() { // ...
```

This annotation is linked with the method **myMeth( )**. Look closely at the annotation syntax. The name of the annotation, preceded by an @, is followed by a parenthesized list of member initializations. To give a member a value, that member’s name is assigned a value. Therefore, in the example, the string "Annotation Example" is assigned to the **str** member of **MyAnno**. Notice that no parentheses follow **str** in this assignment. When an annotation member is given a value, only its name is used. Thus, annotation members look like fields in this context.

Specifying a Retention Policy

Before exploring annotations further, it is necessary to discuss *annotation retention policies*. A retention policy determines at what point an annotation is discarded. Java defines three such policies, which are encapsulated within the **java.lang.annotation.RetentionPolicy** enumeration. They are **SOURCE**, **CLASS**, and **RUNTIME**.

An annotation with a retention policy of **SOURCE** is retained only in the source file and is discarded during compilation.

An annotation with a retention policy of **CLASS** is stored in the **.class** file during compilation. However, it is not available through the JVM during run time.

An annotation with a retention policy of **RUNTIME** is stored in the **.class** file during compilation and is available through the JVM during run time. Thus, **RUNTIME** retention offers the greatest annotation persistence.

NOTE An annotation on a local variable declaration is not retained in the **.class** file.

A retention policy is specified for an annotation by using one of Java's built-in annotations: **@Retention**. Its general form is shown here:

@Retention(*retention-policy*)

Here, *retention-policy* must be one of the previously discussed enumeration constants. If no retention policy is specified for an annotation, then the default policy of **CLASS** is used.

The following version of **MyAnno** uses **@Retention** to specify the **RUNTIME** retention policy. Thus, **MyAnno** will be available to the JVM during program execution.

```
@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
  String str();
  int val();
}
```

Obtaining Annotations at Run Time by Use of Reflection

Although annotations are designed mostly for use by other development or deployment tools, if they specify a retention policy of **RUNTIME**, then they can be queried at run time by any Java program through the use of *reflection*. Reflection is the feature that enables information about a class to be obtained at run time. The reflection API is contained in the **java.lang.reflect** package. There are a number of ways to use reflection, and we won't examine them all here. We will, however, walk through a few examples that apply to annotations.

The first step to using reflection is to obtain a **Class** object that represents the class whose annotations you want to obtain. **Class** is one of Java's built-in

classes and is defined in **java.lang**. It is described in detail in Part II. There are various ways to obtain a **Class** object. One of the easiest is to call **getClass( )**, which is a method defined by **Object**. Its general form is shown here:

final Class<?> getClass( )

It returns the **Class** object that represents the invoking object.

NOTE Notice the **<?>** that follows **Class** in the declaration of **getClass( )** just shown. This is related to Java's generics feature. **getClass( )** and several other reflection-related methods discussed in this chapter make use of generics. Generics are described in Chapter 14. However, an understanding of generics is not needed to grasp the fundamental principles of reflection.

After you have obtained a **Class** object, you can use its methods to obtain information about the various items declared by the class, including its annotations. If you want to obtain the annotations associated with a specific item declared within a class, you must first obtain an object that represents that item. For example, **Class** supplies (among others) the **getMethod( )**, **getField( )**, and **getConstructor( )** methods, which obtain information about a method, field, and constructor, respectively. These methods return objects of type **Method**, **Field**, and **Constructor**.

To understand the process, let's work through an example that obtains the annotations associated with a method. To do this, you first obtain a **Class** object that represents the class, and then call **getMethod( )** on that **Class** object, specifying the name of the method. **getMethod( )** has this general form:

Method getMethod(String *methName*, Class<?> ... *paramTypes*)

The name of the method is passed in *methName*. If the method has arguments, then **Class** objects representing those types must also be specified by *paramTypes*. Notice that *paramTypes* is a varargs parameter. This means that you can specify as many parameter types as needed, including zero. **getMethod( )** returns a **Method** object that represents the method. If the method can't be found, **NoSuchMethodException** is thrown.

From a **Class**, **Method**, **Field**, or **Constructor** object, you can obtain a specific annotation associated with that object by calling **getAnnotation( )**. Its general form is shown here:

<A extends Annotation> getAnnotation(Class<A> *annoType*)

Here, *annoType* is a **Class** object that represents the annotation in which you are

interested. The method returns a reference to the annotation. Using this reference, you can obtain the values associated with the annotation's members. The method returns **null** if the annotation is not found, which will be the case if the annotation does not have **RUNTIME** retention.

Here is a program that assembles all of the pieces shown earlier and uses reflection to display the annotation associated with a method:

```
import java.lang.annotation.*;
import java.lang.reflect.*;

// An annotation type declaration.
@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
  String str();
  int val();
}

class Meta {

  // Annotate a method.
  @MyAnno(str = "Annotation Example", val = 100)
  public static void myMeth() {
    Meta ob = new Meta();

    // Obtain the annotation for this method
    // and display the values of the members.
```

```
    try {
      // First, get a Class object that represents
      // this class.
      Class<?> c = ob.getClass();

      // Now, get a Method object that represents
      // this method.
      Method m = c.getMethod("myMeth");

      // Next, get the annotation for this class.
      MyAnno anno = m.getAnnotation(MyAnno.class);

      // Finally, display the values.
      System.out.println(anno.str() + " " + anno.val());
    } catch (NoSuchMethodException exc) {
      System.out.println("Method Not Found.");
    }
  }

  public static void main(String args[]) {
    myMeth();
  }
}
```

The output from the program is shown here:

```
Annotation Example 100
```

This program uses reflection as described to obtain and display the values of **str** and **val** in the **MyAnno** annotation associated with **myMeth( )** in the **Meta** class. There are two things to pay special attention to. First, in this line

```
MyAnno anno = m.getAnnotation(MyAnno.class);
```

notice the expression **MyAnno.class**. This expression evaluates to a **Class** object of type **MyAnno**, the annotation. This construct is called a *class literal*. You can use this type of expression whenever a **Class** object of a known class is needed. For example, this statement could have been used to obtain the **Class** object for **Meta**:

```
Class<?> c = Meta.class;
```

Of course, this approach only works when you know the class name of an object in advance, which might not always be the case. In general, you can obtain a class literal for classes, interfaces, primitive types, and arrays. (Remember, the **<?>** syntax relates to Java's generics feature. It is described in Chapter 14.)

The second point of interest is the way the values associated with **str** and **val** are obtained when they are output by the following line:

```
System.out.println(anno.str() + " " + anno.val());
```

Notice that they are invoked using the method-call syntax. This same approach is used whenever the value of an annotation member is required.

A Second Reflection Example

In the preceding example, **myMeth( )** has no parameters. Thus, when **getMethod( )** was called, only the name **myMeth** was passed. However, to obtain a method that has parameters, you must specify class objects representing the types of those parameters as arguments to **getMethod( )**. For example, here is a slightly different version of the preceding program:

```
import java.lang.annotation.*;
import java.lang.reflect.*;

@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
  String str();
  int val();
}

class Meta {

  // myMeth now has two arguments.
  @MyAnno(str = "Two Parameters", val = 19)
  public static void myMeth(String str, int i)
  {
    Meta ob = new Meta();

    try {
      Class<?> c = ob.getClass();

      // Here, the parameter types are specified.
      Method m = c.getMethod("myMeth", String.class, int.class);

      MyAnno anno = m.getAnnotation(MyAnno.class);

      System.out.println(anno.str() + " " + anno.val());
    } catch (NoSuchMethodException exc) {
       System.out.println("Method Not Found.");
    }
  }

  public static void main(String args[]) {
    myMeth("test", 10);
  }
}
```

The output from this version is shown here:

```
Two Parameters 19
```

In this version, **myMeth( )** takes a **String** and an **int** parameter. To obtain information about this method, **getMethod( )** must be called as shown here:

```
Method m = c.getMethod("myMeth", String.class, int.class);
```

Here, the **Class** objects representing **String** and **int** are passed as additional arguments.

Obtaining All Annotations

You can obtain all annotations that have **RUNTIME** retention that are associated with an item by calling **getAnnotations( )** on that item. It has this general form:

Annotation[ ] getAnnotations( )

It returns an array of the annotations. **getAnnotations( )** can be called on objects of type **Class**, **Method**, **Constructor**, and **Field**, among others.

Here is another reflection example that shows how to obtain all annotations associated with a class and with a method. It declares two annotations. It then uses those annotations to annotate a class and a method.

```
// Show all annotations for a class and a method.
import java.lang.annotation.*;
import java.lang.reflect.*;

@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
  String str();
  int val();
}

@Retention(RetentionPolicy.RUNTIME)
@interface What {
  String description();
}

@What(description = "An annotation test class")
@MyAnno(str = "Meta2", val = 99)
class Meta2 {

  @What(description = "An annotation test method")
  @MyAnno(str = "Testing", val = 100)
  public static void myMeth() {
    Meta2 ob = new Meta2();

    try {
      Annotation annos[] = ob.getClass().getAnnotations();

      // Display all annotations for Meta2.
      System.out.println("All annotations for Meta2:");
      for(Annotation a : annos)
        System.out.println(a);

      System.out.println();

      // Display all annotations for myMeth.
      Method m = ob.getClass( ).getMethod("myMeth");
      annos = m.getAnnotations();
```

```
      System.out.println("All annotations for myMeth:");
      for(Annotation a : annos)
        System.out.println(a);

    } catch (NoSuchMethodException exc) {
       System.out.println("Method Not Found.");
    }
  }

  public static void main(String args[]) {
    myMeth();
  }
}
```

The output is shown here:

```
All annotations for Meta2:
@What(description=An annotation test class)
@MyAnno(str=Meta2, val=99)

All annotations for myMeth:
@What(description=An annotation test method)
@MyAnno(str=Testing, val=100)
```

The program uses **getAnnotations( )** to obtain an array of all annotations associated with the **Meta2** class and with the **myMeth( )** method. As explained, **getAnnotations( )** returns an array of **Annotation** objects. Recall that **Annotation** is a super-interface of all annotation interfaces and that it overrides **toString( )** in **Object**. Thus, when a reference to an **Annotation** is output, its **toString( )** method is called to generate a string that describes the annotation, as the preceding output shows.

The AnnotatedElement Interface

The methods **getAnnotation( )** and **getAnnotations( )** used by the preceding examples are defined by the **AnnotatedElement** interface, which is defined in **java.lang.reflect**. This interface supports reflection for annotations and is implemented by the classes **Method**, **Field**, **Constructor**, **Class**, and **Package**, among others.

In addition to **getAnnotation( )** and **getAnnotations( )**, **AnnotatedElement** defines several other methods. Two have been available since annotations were

initially added to Java. The first is **getDeclaredAnnotations( )**, which has this general form:

Annotation[ ] getDeclaredAnnotations( )

It returns all non-inherited annotations present in the invoking object. The second is **isAnnotationPresent( )**, which has this general form:

default boolean isAnnotationPresent(Class<? extends Annotation> *annoType*)

It returns **true** if the annotation specified by *annoType* is associated with the invoking object. It returns **false** otherwise. To these, JDK 8 added **getDeclaredAnnotation( )**, **getAnnotationsByType( )**, and **getDeclaredAnnotationsByType( )**. Of these, the last two automatically work with a repeated annotation.(Repeated annotations are discussed at the end of this chapter.)

Using Default Values

You can give annotation members default values that will be used if no value is specified when the annotation is applied. A default value is specified by adding a **default** clause to a member's declaration. It has this general form:

type member( ) default *value* ;

Here, *value* must be of a type compatible with *type*.

Here is **@MyAnno** rewritten to include default values:

```
// An annotation type declaration that includes defaults.
@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
  String str() default "Testing";
  int val() default 9000;
}
```

This declaration gives a default value of "Testing" to **str** and 9000 to **val**. This means that neither value needs to be specified when **@MyAnno** is used. However, either or both can be given values if desired. Therefore, following are the four ways that **@MyAnno** can be used:

```
@MyAnno() // both str and val default
@MyAnno(str = "some string") // val defaults
@MyAnno(val = 100) // str defaults
@MyAnno(str = "Testing", val = 100) // no defaults
```

The following program demonstrates the use of default values in an annotation.

```
import java.lang.annotation.*;
import java.lang.reflect.*;

// An annotation type declaration that includes defaults.
@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
  String str() default "Testing";
  int val() default 9000;
}

class Meta3 {

  // Annotate a method using the default values.
  @MyAnno()
  public static void myMeth() {
    Meta3 ob = new Meta3();

    // Obtain the annotation for this method
    // and display the values of the members.
    try {
      Class<?> c = ob.getClass();

     Method m = c.getMethod("myMeth");
```

```
      MyAnno anno = m.getAnnotation(MyAnno.class);

      System.out.println(anno.str() + " " + anno.val());
    } catch (NoSuchMethodException exc) {
       System.out.println("Method Not Found.");
    }
  }

  public static void main(String args[]) {
    myMeth();
  }
}
```

The output is shown here:

```
Testing 9000
```

Marker Annotations

A *marker* annotation is a special kind of annotation that contains no members. Its sole purpose is to mark an item. Thus, its presence as an annotation is sufficient. The best way to determine if a marker annotation is present is to use the method **isAnnotationPresent( )**, which is defined by the **AnnotatedElement** interface.

Here is an example that uses a marker annotation. Because a marker interface contains no members, simply determining whether it is present or absent is sufficient.

```
import java.lang.annotation.*;
import java.lang.reflect.*;

// A marker annotation.
@Retention(RetentionPolicy.RUNTIME)
@interface MyMarker { }

class Marker {

  // Annotate a method using a marker.
  // Notice that no ( ) is needed.
  @MyMarker
  public static void myMeth() {
    Marker ob = new Marker();

    try {
      Method m = ob.getClass().getMethod("myMeth");

      // Determine if the annotation is present.
      if(m.isAnnotationPresent(MyMarker.class))
        System.out.println("MyMarker is present.");

    } catch (NoSuchMethodException exc) {
      System.out.println("Method Not Found.");
    }
  }

  public static void main(String args[]) {
    myMeth();
  }
}
```

The output, shown here, confirms that **@MyMarker** is present:

```
MyMarker is present.
```

In the program, notice that you do not need to follow **@MyMarker** with parentheses when it is applied. Thus, **@MyMarker** is applied simply by using its name, like this:

```
@MyMarker
```

It is not wrong to supply an empty set of parentheses, but they are not needed.

Single-Member Annotations

A *single-member* annotation contains only one member. It works like a normal annotation except that it allows a shorthand form of specifying the value of the member. When only one member is present, you can simply specify the value for that member when the annotation is applied—you don’t need to specify the name of the member. However, in order to use this shorthand, the name of the member must be **value**.

Here is an example that creates and uses a single-member annotation:

```
import java.lang.annotation.*;
import java.lang.reflect.*;

// A single-member annotation.
@Retention(RetentionPolicy.RUNTIME)
@interface MySingle {
  int value(); // this variable name must be value
}

class Single {

  // Annotate a method using a single-member annotation.
  @MySingle(100)
  public static void myMeth() {
    Single ob = new Single();

    try {
      Method m = ob.getClass().getMethod("myMeth");

      MySingle anno = m.getAnnotation(MySingle.class);

      System.out.println(anno.value()); // displays 100

    } catch (NoSuchMethodException exc) {
       System.out.println("Method Not Found.");
    }
  }

  public static void main(String args[]) {
    myMeth();
  }
}
```

As expected, this program displays the value 100. In the program, **@MySingle** is used to annotate **myMeth( )**, as shown here:

```
@MySingle(100)
```

Notice that **value** = need not be specified.

You can use the single-value syntax when applying an annotation that has

other members, but those other members must all have default values. For example, here the value **xyz** is added, with a default value of zero:

```
@interface SomeAnno {
  int value();
  int xyz() default 0;
}
```

In cases in which you want to use the default for **xyz**, you can apply **@SomeAnno**, as shown next, by simply specifying the value of **value** by using the single-member syntax.

```
@SomeAnno(88)
```

In this case, **xyz** defaults to zero, and **value** gets the value 88. Of course, to specify a different value for **xyz** requires that both members be explicitly named, as shown here:

```
@SomeAnno(value = 88, xyz = 99)
```

Remember, whenever you are using a single-member annotation, the name of that member must be **value**.

The Built-In Annotations

Java defines many built-in annotations. Most are specialized, but nine are general purpose. Of these, four are imported from **java.lang.annotation**: **@Retention**, **@Documented**, **@Target**, and **@Inherited**. Five—**@Override**, **@Deprecated**, **@FunctionalInterface**, **@SafeVarargs**, and **@SuppressWarnings**—are included in **java.lang**. Each is described here.

NOTE **java.lang.annotation** also includes the annotations **Repeatable** and **Native**. **Repeatable** supports repeatable annotations, as described later in this chapter. **Native** annotates a field that can be accessed by native code.

@Retention

@Retention is designed to be used only as an annotation to another annotation. It specifies the retention policy as described earlier in this chapter.

@Documented

The **@Documented** annotation is a marker interface that tells a tool that an annotation is to be documented. It is designed to be used only as an annotation to an annotation declaration.

@Target

The **@Target** annotation specifies the types of items to which an annotation can be applied. It is designed to be used only as an annotation to another annotation. **@Target** takes one argument, which is an array of constants of the **ElementType** enumeration. This argument specifies the types of declarations to which the annotation can be applied. The constants are shown here along with the type of declaration to which they correspond:

Target Constant	Annotation Can Be Applied To
ANNOTATION_TYPE	Another annotation
CONSTRUCTOR	Constructor
FIELD	Field
LOCAL_VARIABLE	Local variable
METHOD	Method
MODULE	Module
PACKAGE	Package
PARAMETER	Parameter
TYPE	Class, interface, or enumeration
TYPE_PARAMETER	Type parameter
TYPE_USE	Type use

You can specify one or more of these values in a **@Target** annotation. To specify multiple values, you must specify them within a braces-delimited list. For example, to specify that an annotation applies only to fields and local variables, you can use this **@Target** annotation:

```
@Target( { ElementType.FIELD, ElementType.LOCAL_VARIABLE } )
```

If you don't use **@Target**, then, except for type parameters, the annotation can be used on any declaration. For this reason, it is often a good idea to explicitly specify the target or targets so as to clearly indicate the intended uses of an annotation.

@Inherited

@Inherited is a marker annotation that can be used only on another annotation declaration. Furthermore, it affects only annotations that will be used on class declarations. **@Inherited** causes the annotation for a superclass to be inherited by a subclass. Therefore, when a request for a specific annotation is made to the subclass, if that annotation is not present in the subclass, then its superclass is checked. If that annotation is present in the superclass, and if it is annotated with **@Inherited**, then that annotation will be returned.

@Override

@Override is a marker annotation that can be used only on methods. A method annotated with **@Override** must override a method from a superclass. If it doesn't, a compile-time error will result. It is used to ensure that a superclass method is actually overridden, and not simply overloaded.

@Deprecated

@Deprecated indicates that a declaration is obsolete and not recommended for use. Beginning with JDK 9, **@Deprecated** also allows you to specify the Java version in which the deprecation occurred and whether the deprecated element is slated for removal.

@FunctionalInterface

@FunctionalInterface is a marker annotation designed for use on interfaces. It indicates that the annotated interface is a functional interface. A *functional interface* is an interface that contains one and only one abstract method. Functional interfaces are used by lambda expressions. (See Chapter 15 for details on functional interfaces and lambda expressions.) If the annotated interface is not a functional interface, a compilation error will be reported. It is important to understand that **@FunctionalInterface** is not needed to create a functional interface. Any interface with exactly one abstract method is, by definition, a functional interface. Thus, **@FunctionalInterface** is purely informational.

@SafeVarargs

@SafeVarargs is a marker annotation that can be applied to methods and constructors. It indicates that no unsafe actions related to a varargs parameter

occur. It is used to suppress unchecked warnings on otherwise safe code as it relates to non-reifiable vararg types and parameterized array instantiation. (A non-reifiable type is, essentially, a generic type. Generics are described in Chapter 14.) It must be applied only to vararg methods or constructors. Methods must also be **static**, **final**, or **private**.

@SuppressWarnings

@SuppressWarnings specifies that one or more warnings that might be issued by the compiler are to be suppressed. The warnings to suppress are specified by name, in string form.

Type Annotations

Beginning with JDK 8, the places in which annotations can be used has been expanded. As mentioned earlier, annotations were originally allowed only on declarations. However, now, annotations can also be specified in most cases in which a type is used. This expanded aspect of annotations is called *type annotation*. For example, you can annotate the return type of a method, the type of **this** within a method, a cast, array levels, an inherited class, and a **throws** clause. You can also annotate generic types, including generic type parameter bounds and generic type arguments. (See Chapter 14 for a discussion of generics.)

Type annotations are important because they enable tools to perform additional checks on code to help prevent errors. Understand that, as a general rule, **javac** will not perform these checks, itself. A separate tool is used for this purpose, although such a tool might operate as a compiler plug-in.

A type annotation must include **ElementType.TYPE_USE** as a target. (Recall that valid annotation targets are specified using the **@Target** annotation, as previously described.) A type annotation applies to the type that the annotation precedes. For example, assuming some type annotation called **@TypeAnno**, the following is legal:

```
void myMeth() throws @TypeAnno NullPointerException { // ...
```

Here, @**TypeAnno** annotates **NullPointerException** in the **throws** clause.

You can also annotate the type of **this** (called the *receiver*). As you know, **this** is an implicit argument to all instance methods and it refers to the invoking object. To annotate its type requires the use of another recently added feature.

Beginning with JDK 8, you can explicitly declare **this** as the first parameter to a method. In this declaration, the type of **this** must be the type of its class; for example:

```
class SomeClass {
  int myMeth(SomeClass this, int i, int j) { // ...
```

Here, because **myMeth( )** is a method defined by **SomeClass**, the type of **this** is **SomeClass**. Using this declaration, you can now annotate the type of **this**. For example, again assuming that **@TypeAnno** is a type annotation, the following is legal:

```
int myMeth(@TypeAnno SomeClass this, int i, int j) { // ...
```

It is important to understand that it is not necessary to declare **this** unless you are annotating it. (If **this** is not declared, it is still implicitly passed, as it always has been.) Also, explicitly declaring **this** does not change any aspect of the method's signature because **this** is implicitly declared, by default. Again, you will declare **this** only if you want to apply a type annotation to it. If you do declare **this**, it *must* be the first parameter.

The following program shows a number of the places that a type annotation can be used. It defines several annotations, of which several are for type annotation. The names and targets of the annotations are shown here:

Annotation	Target
@TypeAnno	ElementType.TYPE_USE
@MaxLen	ElementType.TYPE_USE
@NotZeroLen	ElementType.TYPE_USE
@Unique	ElementType.TYPE_USE
@What	ElementType.TYPE_PARAMETER
@EmptyOK	ElementType.FIELD
@Recommended	ElementType.METHOD

Notice that **@EmptyOK**, **@Recommended**, and **@What** are not type annotations. They are included for comparison purposes. Of special interest is **@What**, which is used to annotate a generic type parameter declaration. The comments in the program describe each use.

```
// Demonstrate several type annotations.
import java.lang.annotation.*;
import java.lang.reflect.*;

// A marker annotation that can be applied to a type.
@Target(ElementType.TYPE_USE)
@interface TypeAnno { }

// Another marker annotation that can be applied to a type.
@Target(ElementType.TYPE_USE)
@interface NotZeroLen {
}

// Still another marker annotation that can be applied to a type.
@Target(ElementType.TYPE_USE)
@interface Unique { }

// A parameterized annotation that can be applied to a type.
@Target(ElementType.TYPE_USE)
@interface MaxLen {
  int value();
}

// An annotation that can be applied to a type parameter.
@Target(ElementType.TYPE_PARAMETER)
@interface What {
  String description();
}

// An annotation that can be applied to a field declaration.
@Target(ElementType.FIELD)
@interface EmptyOK { }

// An annotation that can be applied to a method declaration.
@Target(ElementType.METHOD)
@interface Recommended { }


// Use an annotation on a type parameter.
class TypeAnnoDemo<@What(description = "Generic data type") T> {

  // Use a type annotation on a constructor.
  public @Unique TypeAnnoDemo() {}

  // Annotate the type (in this case String), not the field.
  @TypeAnno String str;
```

```
  // This annotates the field test.
  @EmptyOK String test;

  // Use a type annotation to annotate this (the receiver).
  public int f(@TypeAnno TypeAnnoDemo<T> this, int x) {
    return 10;
  }

  // Annotate the return type.
  public @TypeAnno Integer f2(int j, int k) {
    return j+k;
  }

  // Annotate the method declaration.
  public @Recommended Integer f3(String str) {
    return str.length() / 2;
  }

  // Use a type annotation with a throws clause.
  public void f4() throws @TypeAnno NullPointerException {
    // ...
  }

  // Annotate array levels.
  String @MaxLen(10) [] @NotZeroLen [] w;

  // Annotate the array element type.
  @TypeAnno Integer[] vec;

  public static void myMeth(int i) {

    // Use a type annotation on a type argument.
    TypeAnnoDemo<@TypeAnno Integer> ob =
                              new TypeAnnoDemo<@TypeAnno Integer>();

    // Use a type annotation with new.
    @Unique TypeAnnoDemo<Integer> ob2 = new @Unique TypeAnnoDemo<Integer>();

    Object x = Integer.valueOf(10);
    Integer y;

    // Use a type annotation on a cast.
    y = (@TypeAnno Integer) x;
  }

  public static void main(String args[]) {
    myMeth(10);
  }

  // Use type annotation with inheritance clause.
  class SomeClass extends @TypeAnno TypeAnnoDemo<Boolean> {}
}
```

Although what most of the annotations in the preceding program refer to is clear, four uses require a bit of discussion. The first is the annotation of a method return type versus the annotation of a method declaration. In the program, pay special attention to these two method declarations:

```
// Annotate the return type.
public @TypeAnno Integer f2(int j, int k) {
  return j+k;
}

// Annotate the method declaration.
public @Recommended Integer f3(String str) {
  return str.length() / 2;
}
```

Notice that in both cases, an annotation precedes the method's return type (which is **Integer**). However, the two annotations annotate two different things. In the first case, the **@TypeAnno** annotation annotates **f2( )**'s return type. This is because **@TypeAnno** has its target specified as **ElementType.TYPE_USE**, which means that it can be used to annotate type uses. In the second case, **@Recommended** annotates the method declaration, itself. This is because **@Recommended** has its target specified as **ElementType.METHOD**. As a result, **@Recommended** applies to the declaration, not the return type. Therefore, the target specification is used to eliminate what, at first glance, appears to be ambiguity between the annotation of a method declaration and the annotation of the method's return type.

One other thing about annotating a method return type: You cannot annotate a return type of **void**.

The second point of interest are the field annotations, shown here:

```
// Annotate the type (in this case String), not the field.
@TypeAnno String str;

// This annotates the field test.
@EmptyOK String test;
```

Here, **@TypeAnno** annotates the type **String**, but **@EmptyOK** annotates the field **test**. Even though both annotations precede the entire declaration, their targets are different, based on the target element type. If the annotation has the

ElementType.TYPE_USE target, then the type is annotated. If it has **ElementType.FIELD** as a target, then the field is annotated. Thus, the situation is similar to that just described for methods, and no ambiguity exists. The same mechanism also disambiguates annotations on local variables.

Next, notice how **this** (the receiver) is annotated here:

```
public int f(@TypeAnno TypeAnnoDemo<T> this, int x) {
```

Here, **this** is specified as the first parameter and is of type **TypeAnnoDemo** (which is the class of which **f( )** is a member). As explained, beginning with JDK 8, an instance method declaration can explicitly specify the **this** parameter for the sake of applying a type annotation.

Finally, look at how array levels are annotated by the following statement:

```
String @MaxLen(10) [] @NotZeroLen [] w;
```

In this declaration, **@MaxLen** annotates the type of the first level and **@NotZeroLen** annotates the type of the second level. In this declaration

```
@TypeAnno Integer[] vec;
```

the element type **Integer** is annotated.

Repeating Annotations

Beginning with JDK 8, an annotation can be repeated on the same element. This is called *repeating annotations*. For an annotation to be repeatable, it must be annotated with the **@Repeatable** annotation, defined in **java.lang.annotation**. Its **value** field specifies the *container* type for the repeatable annotation. The container is specified as an annotation for which the **value** field is an array of the repeatable annotation type. Thus, to create a repeatable annotation, you must create a container annotation and then specify that annotation type as an argument to the **@Repeatable** annotation.

To access the repeated annotations using a method such as **getAnnotation( )**, you will use the container annotation, not the repeatable annotation. The following program shows this approach. It converts the version of **MyAnno** shown previously into a repeatable annotation and demonstrates its use.

```
// Demonstrate a repeated annotation.

import java.lang.annotation.*;
import java.lang.reflect.*;

// Make MyAnno repeatable.
@Retention(RetentionPolicy.RUNTIME)
@Repeatable(MyRepeatedAnnos.class)
@interface MyAnno {
  String str() default "Testing";
  int val() default 9000;
}

// This is the container annotation.
@Retention(RetentionPolicy.RUNTIME)
@interface MyRepeatedAnnos {
  MyAnno[] value();
}

class RepeatAnno {

  // Repeat MyAnno on myMeth().
  @MyAnno(str = "First annotation", val = -1)
  @MyAnno(str = "Second annotation", val = 100)
  public static void myMeth(String str, int i)
```

```
  {
    RepeatAnno ob = new RepeatAnno();

    try {
      Class<?> c = ob.getClass();

      // Obtain the annotations for myMeth().
      Method m = c.getMethod("myMeth", String.class, int.class);

      // Display the repeated MyAnno annotations.
      Annotation anno = m.getAnnotation(MyRepeatedAnnos.class);
      System.out.println(anno);

    } catch (NoSuchMethodException exc) {
       System.out.println("Method Not Found.");
    }
  }

  public static void main(String args[]) {
    myMeth("test", 10);
  }
}
```

The output is shown here:

```
@MyRepeatedAnnos(value={@MyAnno(val=-1, str="First annotation"),
@MyAnno(val=100, str="Second annotation")})
```

As explained, in order for **MyAnno** to be repeatable, it must be annotated with the **@Repeatable** annotation, which specifies its container annotation. The container annotation is called **MyRepeatedAnnos**. The program accesses the repeated annotations by calling **getAnnotation( )**, passing in the class of the container annotation, not the repeatable annotation, itself. As the output shows, the repeated annotations are separated by a comma. They are not returned individually.

Another way to obtain the repeated annotations is to use one of the methods in **AnnotatedElement** that can operate directly on a repeated annotation. These are **getAnnotationsByType( )** and **getDeclaredAnnotationsByType( )**. Here, we will use the former. It is shown here:

```
default <T extends Annotation> T[ ] getAnnotationsByType(Class<T>
annoType)
```

It returns an array of the annotations of *annoType* associated with the invoking object. If no annotations are present, the array will be of zero length. Here is an example. Assuming the preceding program, the following sequence uses **getAnnotationsByType( )** to obtain the repeated **MyAnno** annotations:

```
Annotation[] annos = m.getAnnotationsByType(MyAnno.class);
for(Annotation a : annos)
  System.out.println(a);
```

Here, the repeated annotation type, which is **MyAnno**, is passed to **getAnnotationsByType( )**. The returned array contains all of the instances of **MyAnno** associated with **myMeth( )**, which, in this example, is two. Each repeated annotation can be accessed via its index in the array. In this case, each **MyAnno** annotation is displayed via a for-each loop.

Some Restrictions

There are a number of restrictions that apply to annotation declarations. First, no annotation can inherit another. Second, all methods declared by an annotation must be without parameters. Furthermore, they must return one of the following:

- A primitive type, such as **int** or **double**
- An object of type **String** or **Class**
- An object of an **enum** type
- An object of another annotation type
- An array of a legal type.

Annotations cannot be generic. In other words, they cannot take type parameters. (Generics are described in Chapter 14.) Finally, annotation methods cannot specify a **throws** clause.

CHAPTER

13

I/O, Try-with-Resources, and Other Topics

This chapter introduces one of Java's most important packages, **java.io**, which supports Java's basic I/O (input/output) system, including file I/O. Support for I/O comes from Java's core API libraries, not from language keywords. For this reason, an in-depth discussion of this topic is found in Part II of this book, which examines several of Java's API packages. Here, the foundation of this important subsystem is introduced so that you can see how it fits into the larger context of the Java programming and execution environment. This chapter also examines the **try**-with-resources statement and several more Java keywords: **transient**, **volatile**, **instanceof**, **native**, **strictfp**, and **assert**. It concludes by discussing static import and describing another use for the **this** keyword.

I/O Basics

As you may have noticed while reading the preceding 12 chapters, not much use has been made of I/O in the example programs. In fact, aside from **print( )** and **println( )**, none of the I/O methods have been used significantly. The reason is simple: most real applications of Java are not text-based, console programs. Rather, they are either graphically oriented programs that rely on one of Java's graphical user interface (GUI) frameworks, such as Swing, the AWT, or JavaFX, for user interaction, or they are Web applications. Although text-based, console programs are excellent as teaching examples, they do not, as a general rule, constitute an important use for Java in the real world. Also, Java's support for console I/O is limited and somewhat awkward to use—even in simple example programs. Text-based console I/O is just not that useful in real-world Java programming.

The preceding paragraph notwithstanding, Java does provide strong, flexible support for I/O as it relates to files and networks. Java's I/O system is cohesive and consistent. In fact, once you understand its fundamentals, the rest of the I/O system is easy to master. A general overview of I/O is presented here. A detailed description is found in Chapters 21 and 22.

Streams

Java programs perform I/O through streams. A *stream* is an abstraction that either produces or consumes information. A stream is linked to a physical device by the Java I/O system. All streams behave in the same manner, even if the actual physical devices to which they are linked differ. Thus, the same I/O classes and methods can be applied to different types of devices. This means that an input stream can abstract many different kinds of input: from a disk file, a keyboard, or a network socket. Likewise, an output stream may refer to the console, a disk file, or a network connection. Streams are a clean way to deal with input/output without having every part of your code understand the difference between a keyboard and a network, for example. Java implements streams within class hierarchies defined in the **java.io** package.

NOTE In addition to the stream-based I/O defined in **java.io**, Java also provides buffer- and channel-based I/O, which is defined in **java.nio** and its subpackages. They are described in Chapter 22.

Byte Streams and Character Streams

Java defines two types of streams: byte and character. *Byte streams* provide a convenient means for handling input and output of bytes. Byte streams are used, for example, when reading or writing binary data. *Character streams* provide a convenient means for handling input and output of characters. They use Unicode and, therefore, can be internationalized. Also, in some cases, character streams are more efficient than byte streams.

The original version of Java (Java 1.0) did not include character streams and, thus, all I/O was byte-oriented. Character streams were added by Java 1.1, and certain byte-oriented classes and methods were deprecated. Although old code that doesn't use character streams is becoming increasingly rare, it may still be encountered from time to time. As a general rule, old code should be updated to take advantage of character streams where appropriate.

One other point: at the lowest level, all I/O is still byte-oriented. The character-based streams simply provide a convenient and efficient means for handling characters.

An overview of both byte-oriented streams and character-oriented streams is presented in the following sections.

The Byte Stream Classes

Byte streams are defined by using two class hierarchies. At the top are two

abstract classes: **InputStream** and **OutputStream**. Each of these abstract classes has several concrete subclasses that handle the differences among various devices, such as disk files, network connections, and even memory buffers. The byte stream classes in **java.io** are shown in Table 13-1. A few of these classes are discussed later in this section. Others are described in Part II of this book. Remember, to use the stream classes, you must import **java.io**.

Stream Class	Meaning
BufferedInputStream	Buffered input stream
BufferedOutputStream	Buffered output stream
ByteArrayInputStream	Input stream that reads from a byte array
ByteArrayOutputStream	Output stream that writes to a byte array
DataInputStream	An input stream that contains methods for reading the Java standard data types
DataOutputStream	An output stream that contains methods for writing the Java standard data types
FileInputStream	Input stream that reads from a file
FileOutputStream	Output stream that writes to a file
FilterInputStream	Implements **InputStream**
FilterOutputStream	Implements **OutputStream**
InputStream	Abstract class that describes stream input
ObjectInputStream	Input stream for objects
ObjectOutputStream	Output stream for objects
OutputStream	Abstract class that describes stream output
PipedInputStream	Input pipe
PipedOutputStream	Output pipe
PrintStream	Output stream that contains **print( )** and **println( )**
PushbackInputStream	Input stream that allows bytes to be returned to the input stream.
SequenceInputStream	Input stream that is a combination of two or more input streams that will be read sequentially, one after the other

Table 13-1 The Byte Stream Classes in **java.io**

The abstract classes **InputStream** and **OutputStream** define several key methods that the other stream classes implement. Two of the most important are

read( ) and **write( )**, which, respectively, read and write bytes of data. Each has a form that is abstract and must be overridden by derived stream classes.

The Character Stream Classes

Character streams are defined by using two class hierarchies. At the top are two abstract classes: **Reader** and **Writer**. These abstract classes handle Unicode character streams. Java has several concrete subclasses of each of these. The character stream classes in **java.io** are shown in Table 13-2.

Stream Class	Meaning
BufferedReader	Buffered input character stream
BufferedWriter	Buffered output character stream
CharArrayReader	Input stream that reads from a character array
CharArrayWriter	Output stream that writes to a character array
FileReader	Input stream that reads from a file
FileWriter	Output stream that writes to a file
FilterReader	Filtered reader
FilterWriter	Filtered writer
InputStreamReader	Input stream that translates bytes to characters
LineNumberReader	Input stream that counts lines
OutputStreamWriter	Output stream that translates characters to bytes
PipedReader	Input pipe
PipedWriter	Output pipe
PrintWriter	Output stream that contains **print( )** and **println( )**
PushbackReader	Input stream that allows characters to be returned to the input stream
Reader	Abstract class that describes character stream input
StringReader	Input stream that reads from a string
StringWriter	Output stream that writes to a string
Writer	Abstract class that describes character stream output

Table 13-2 The Character Stream I/O Classes in **java.io**

The abstract classes **Reader** and **Writer** define several key methods that the other stream classes implement. Two of the most important methods are **read( )**

and **write( )**, which read and write characters of data, respectively. Each has a form that is abstract and must be overridden by derived stream classes.

The Predefined Streams

As you know, all Java programs automatically import the **java.lang** package. This package defines a class called **System**, which encapsulates several aspects of the run-time environment. For example, using some of its methods, you can obtain the current time and the settings of various properties associated with the system. **System** also contains three predefined stream variables: **in**, **out**, and **err**. These fields are declared as **public**, **static**, and **final** within **System**. This means that they can be used by any other part of your program and without reference to a specific **System** object.

System.out refers to the standard output stream. By default, this is the console. **System.in** refers to standard input, which is the keyboard by default. **System.err** refers to the standard error stream, which also is the console by default. However, these streams may be redirected to any compatible I/O device.

System.in is an object of type **InputStream**; **System.out** and **System.err** are objects of type **PrintStream**. These are byte streams, even though they are typically used to read and write characters from and to the console. As you will see, you can wrap these within character-based streams, if desired.

The preceding chapters have been using **System.out** in their examples. You can use **System.err** in much the same way. As explained in the next section, use of **System.in** is a little more complicated.

Reading Console Input

In the early days of Java, the only way to perform console input was to use a byte stream. Today, using a byte stream to read console input is still acceptable. However, for commercial applications, the preferred method of reading console input is to use a character-oriented stream. This makes your program easier to internationalize and maintain.

In Java, console input is accomplished by reading from **System.in**. To obtain a character-based stream that is attached to the console, wrap **System.in** in a **BufferedReader** object. **BufferedReader** supports a buffered input stream. A commonly used constructor is shown here:

BufferedReader(Reader *inputReader*)

Here, *inputReader* is the stream that is linked to the instance of **BufferedReader** that is being created. **Reader** is an abstract class. One of its concrete subclasses is **InputStreamReader**, which converts bytes to characters. To obtain an **InputStreamReader** object that is linked to **System.in**, use the following constructor:

InputStreamReader(InputStream *inputStream*)

Because **System.in** refers to an object of type **InputStream**, it can be used for *inputStream*. Putting it all together, the following line of code creates a **BufferedReader** that is connected to the keyboard:

```
BufferedReader br = new BufferedReader(new
                        InputStreamReader(System.in));
```

After this statement executes, **br** is a character-based stream that is linked to the console through **System.in**.

Reading Characters

To read a character from a **BufferedReader**, use **read( )**. The version of **read( )** that we will be using is

int read( ) throws IOException

Each time that **read( )** is called, it reads a character from the input stream and returns it as an integer value. It returns –1 when an attempt is made to read at the end of the stream. As you can see, it can throw an **IOException**.

The following program demonstrates **read( )** by reading characters from the console until the user types a "q." Notice that any I/O exceptions that might be generated are simply thrown out of **main( )**. Such an approach is common when reading from the console in simple example programs such as those shown in this book, but in more sophisticated applications, you can handle the exceptions explicitly.

```
// Use a BufferedReader to read characters from the console.
import java.io.*;

class BRRead {
  public static void main(String args[]) throws IOException
  {
    char c;
    BufferedReader br = new
            BufferedReader(new InputStreamReader(System.in));
    System.out.println("Enter characters, 'q' to quit.");
    // read characters
    do {
      c = (char) br.read();
      System.out.println(c);
    } while(c != 'q');
  }
}
```

Here is a sample run:

```
Enter characters, 'q' to quit.
123abcq
1
2
3
a
b
c
q
```

This output may look a little different from what you expected because **System.in** is line buffered, by default. This means that no input is actually passed to the program until you press enter. As you can guess, this does not make **read( )** particularly valuable for interactive console input.

Reading Strings

To read a string from the keyboard, use the version of **readLine( )** that is a member of the **BufferedReader** class. Its general form is shown here:

String readLine( ) throws IOException

As you can see, it returns a **String** object.

The following program demonstrates **BufferedReader** and the **readLine( )** method; the program reads and displays lines of text until you enter the word "stop":

```
// Read a string from console using a BufferedReader.
import java.io.*;

class BRReadLines {
  public static void main(String args[]) throws IOException
  {
    // create a BufferedReader using System.in
    BufferedReader br = new BufferedReader(new
                            InputStreamReader(System.in));
    String str;
    System.out.println("Enter lines of text.");
    System.out.println("Enter 'stop' to quit.");
    do {
      str = br.readLine();
      System.out.println(str);
    } while(!str.equals("stop"));
  }
}
```

The next example creates a tiny text editor. It creates an array of **String** objects and then reads in lines of text, storing each line in the array. It will read up to 100 lines or until you enter "stop." It uses a **BufferedReader** to read from the console.

```
// A tiny editor.
import java.io.*;

class TinyEdit {
  public static void main(String args[]) throws IOException
  {
    // create a BufferedReader using System.in
    BufferedReader br = new BufferedReader(new
                            InputStreamReader(System.in));
    String str[] = new String[100];
    System.out.println("Enter lines of text.");
    System.out.println("Enter 'stop' to quit.");
    for(int i=0; i<100; i++) {
      str[i] = br.readLine();
      if(str[i].equals("stop")) break;
    }
    System.out.println("\nHere is your file:");
    // display the lines
    for(int i=0; i<100; i++) {
      if(str[i].equals("stop")) break;
      System.out.println(str[i]);
    }
  }
}
```

Here is a sample run:

```
Enter lines of text.
Enter 'stop' to quit.
This is line one.
This is line two.
Java makes working with strings easy.
Just create String objects.
stop
Here is your file:
This is line one.
This is line two.
Java makes working with strings easy.
Just create String objects.
```

Writing Console Output

Console output is most easily accomplished with **print( )** and **println( )**, described earlier, which are used in most of the examples in this book. These methods are defined by the class **PrintStream** (which is the type of object referenced by **System.out**). Even though **System .out** is a byte stream, using it for simple program output is still acceptable. However, a character-based alternative is described in the next section.

Because **PrintStream** is an output stream derived from **OutputStream**, it also implements the low-level method **write( )**. Thus, **write( )** can be used to write to the console. The simplest form of **write( )** defined by **PrintStream** is shown here:

void write(int *byteval*)

This method writes the byte specified by *byteval*. Although *byteval* is declared as an integer, only the low-order eight bits are written. Here is a short example that uses **write( )** to output the character "A" followed by a newline to the screen:

```
// Demonstrate System.out.write().
class WriteDemo {
  public static void main(String args[]) {
    int b;

    b = 'A';
    System.out.write(b);
    System.out.write('\n');
  }
}
```

You will not often use **write( )** to perform console output (although doing so might be useful in some situations) because **print( )** and **println( )** are substantially easier to use.

The PrintWriter Class

Although using **System.out** to write to the console is acceptable, its use is probably best for debugging purposes or for sample programs, such as those found in this book. For real-world programs, the recommended method of writing to the console when using Java is through a **PrintWriter** stream. **PrintWriter** is one of the character-based classes. Using a character-based class

for console output makes internationalizing your program easier.

PrintWriter defines several constructors. The one we will use is shown here:

PrintWriter(OutputStream *outputStream*, boolean *flushingOn*)

Here, *outputStream* is an object of type **OutputStream**, and *flushingOn* controls whether Java flushes the output stream every time a **println( )** method (among others) is called. If *flushingOn* is **true**, flushing automatically takes place. If **false**, flushing is not automatic.

PrintWriter supports the **print( )** and **println( )** methods. Thus, you can use these methods in the same way as you used them with **System.out**. If an argument is not a simple type, the **PrintWriter** methods call the object's **toString( )** method and then display the result.

To write to the console by using a **PrintWriter**, specify **System.out** for the output stream and automatic flushing. For example, this line of code creates a **PrintWriter** that is connected to console output:

```
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);

    pw.println("This is a string");
    int i = -7;
    pw.println(i);
    double d = 4.5e-7;
    pw.println(d);
  }
}
```

The output from this program is shown here:

```
This is a string
```

```
-7
4.5E-7
```

Remember, there is nothing wrong with using **System.out** to write simple text output to the console when you are learning Java or debugging your programs. However, using a **PrintWriter** makes your real-world applications easier to internationalize. Because no advantage is gained by using a **PrintWriter** in the sample programs shown in this book, we will continue to use **System.out** to write to the console.

Reading and Writing Files

Java provides a number of classes and methods that allow you to read and write files. Before we begin, it is important to state that the topic of file I/O is quite large and file I/O is examined in detail in Part II. The purpose of this section is to introduce the basic techniques that read from and write to a file. Although byte streams are used, these techniques can be adapted to the character-based streams.

Two of the most often-used stream classes are **FileInputStream** and **FileOutputStream**, which create byte streams linked to files. To open a file, you simply create an object of one of these classes, specifying the name of the file as an argument to the constructor. Although both classes support additional constructors, the following are the forms that we will be using:

FileInputStream(String *fileName*) throws FileNotFoundException
FileOutputStream(String *fileName*) throws FileNotFoundException

Here, *fileName* specifies the name of the file that you want to open. When you create an input stream, if the file does not exist, then **FileNotFoundException** is thrown. For output streams, if the file cannot be opened or created, then **FileNotFoundException** is thrown. **FileNotFoundException** is a subclass of **IOException**. When an output file is opened, any preexisting file by the same name is destroyed.

NOTE In situations in which a security manager is present, several of the file classes, including **FileInputStream** and **FileOutputStream**, will throw a **SecurityException** if a security violation occurs when attempting to open a file. By default, applications run via **java** do not use a security manager. For that reason, the I/O examples in this book do not need to watch for a possible **SecurityException**. However, other types of applications may use the security manager, and file I/O performed by such an application could generate a **SecurityException**. In that case, you will need to appropriately handle this exception.

When you are done with a file, you must close it. This is done by calling the **close( )** method, which is implemented by both **FileInputStream** and **FileOutputStream**. It is shown here:

```
void close( ) throws IOException
```

Closing a file releases the system resources allocated to the file, allowing them to be used by another file. Failure to close a file can result in "memory leaks" because of unused resources remaining allocated.

NOTE The **close( )** method is specified by the **AutoCloseable** interface in **java.lang**. **AutoCloseable** is inherited by the **Closeable** interface in **java.io**. Both interfaces are implemented by the stream classes, including **FileInputStream** and **FileOutputStream**.

Before moving on, it is important to point out that there are two basic approaches that you can use to close a file when you are done with it. The first is the traditional approach, in which **close( )** is called explicitly when the file is no longer needed. This is the approach used by all versions of Java prior to JDK 7 and is, therefore, found in all pre-JDK 7 legacy code. The second is to use the **try**-with-resources statement added by JDK 7, which automatically closes a file when it is no longer needed. In this approach, no explicit call to **close( )** is executed. Since you may still encounter pre-JDK 7 legacy code, it is important that you know and understand the traditional approach. Furthermore, the traditional approach could still be the best approach in some situations. Therefore, we will begin with it. The automated approach is described in the following section.

To read from a file, you can use a version of **read( )** that is defined within **FileInputStream**. The one that we will use is shown here:

```
int read( ) throws IOException
```

Each time that it is called, it reads a single byte from the file and returns the byte as an integer value. **read( )** returns –1 when an attempt is made to read at the end of the stream. It can throw an **IOException**.

The following program uses **read( )** to input and display the contents of a file that contains ASCII text. The name of the file is specified as a command-line argument.

```
/* Display a text file.
   To use this program, specify the name
   of the file that you want to see.
   For example, to see a file called TEST.TXT,
   use the following command line.

   java ShowFile TEST.TXT
*/

import java.io.*;

class ShowFile {
  public static void main(String args[])
  {
    int i;
    FileInputStream fin;

    // First, confirm that a filename has been specified.
    if(args.length != 1) {
      System.out.println("Usage: ShowFile filename");
      return;
    }

    // Attempt to open the file.
    try {
      fin = new FileInputStream(args[0]);
    } catch(FileNotFoundException e) {
      System.out.println("Cannot Open File");
      return;
    }

    // At this point, the file is open and can be read.
    // The following reads characters until EOF is encountered.
    try {
      do {
        i = fin.read();
        if(i != -1) System.out.print((char) i);
      } while(i != -1);
    } catch(IOException e) {
      System.out.println("Error Reading File");
   }

    // Close the file.
    try {
      fin.close();
    } catch(IOException e) {
        System.out.println("Error Closing File");
    }
  }
}
```

In the program, notice the **try/catch** blocks that handle the I/O errors that might occur. Each I/O operation is monitored for exceptions, and if an exception occurs, it is handled. Be aware that in simple programs or example code, it is common to see I/O exceptions simply thrown out of **main( )**, as was done in the earlier console I/O examples. Also, in some real-world code, it can be helpful to let an exception propagate to a calling routine to let the caller know that an I/O operation failed. However, most of the file I/O examples in this book handle all I/O exceptions explicitly, as shown, for the sake of illustration.

Although the preceding example closes the file stream after the file is read, there is a variation that is often useful. The variation is to call **close( )** within a **finally** block. In this approach, all of the methods that access the file are contained within a **try** block, and the **finally** block is used to close the file. This way, no matter how the **try** block terminates, the file is closed. Assuming the preceding example, here is how the **try** block that reads the file can be recoded:

```
/* Display a text file.
   To use this program, specify the name
   of the file that you want to see.
   For example, to see a file called TEST.TXT,
   use the following command line.

   java ShowFile TEST.TXT

   This variation wraps the code that opens and
   accesses the file within a single try block.
   The file is closed by the finally block.
*/
```

Although not an issue in this case, one advantage to this approach in general is that if the code that accesses a file terminates because of some non-I/O related exception, the file is still closed by the **finally** block.

Sometimes it’s easier to wrap the portions of a program that open the file and access the file within a single **try** block (rather than separating the two) and then use a **finally** block to close the file. For example, here is another way to write the **ShowFile** program:

```
/* Display a text file.
   To use this program, specify the name
   of the file that you want to see.
   For example, to see a file called TEST.TXT,
   use the following command line.

   java ShowFile TEST.TXT

   This variation wraps the code that opens and
   accesses the file within a single try block.
   The file is closed by the finally block.
*/
```

```
import java.io.*;

class ShowFile {
  public static void main(String args[])
  {
    int i;
    FileInputStream fin = null;

    // First, confirm that a filename has been specified.
    if(args.length != 1) {
      System.out.println("Usage: ShowFile filename");
      return;
    }

    // The following code opens a file, reads characters until EOF
    // is encountered, and then closes the file via a finally block.
    try {
      fin = new FileInputStream(args[0]);

      do {
        i = fin.read();
        if(i != -1) System.out.print((char) i);
      } while(i != -1);

    } catch(FileNotFoundException e) {
      System.out.println("File Not Found.");
    } catch(IOException e) {
      System.out.println("An I/O Error Occurred");
    } finally {
      // Close file in all cases.
      try {
        if(fin != null) fin.close();
      } catch(IOException e) {
        System.out.println("Error Closing File");
      }
    }
  }
}
```

In this approach, notice that **fin** is initialized to **null**. Then, in the **finally** block, the file is closed only if **fin** is not **null**. This works because **fin** will be non-**null**

only if the file is successfully opened. Thus, **close( )** is not called if an exception occurs while opening the file.

It is possible to make the **try/catch** sequence in the preceding example a bit more compact. Because **FileNotFoundException** is a subclass of **IOException**, it need not be caught separately. For example, here is the sequence recoded to eliminate catching **FileNotFoundException**. In this case, the standard exception message, which describes the error, is displayed.

```
try {
  fin = new FileInputStream(args[0]);

  do {

    i = fin.read();
    if(i != -1) System.out.print((char) i);
  } while(i != -1);

} catch(IOException e) {
  System.out.println("I/O Error: " + e);
} finally {
  // Close file in all cases.
  try {
    if(fin != null) fin.close();
  } catch(IOException e) {
    System.out.println("Error Closing File");
  }
}
```

In this approach, any error, including an error opening the file, is simply handled by the single **catch** statement. Because of its compactness, this approach is used by many of the I/O examples in this book. Be aware, however, that this approach is not appropriate in cases in which you want to deal separately with a failure to open a file, such as might be caused if a user mistypes a filename. In such a situation, you might want to prompt for the correct name, for example, before entering a **try** block that accesses the file.

To write to a file, you can use the **write( )** method defined by **FileOutputStream**. Its simplest form is shown here:

void write(int *byteval*) throws IOException

This method writes the byte specified by *byteval* to the file. Although *byteval* is declared as an integer, only the low-order eight bits are written to the file. If an error occurs during writing, an **IOException** is thrown. The next example uses **write( )** to copy a file:

```
/* Copy a file.
   To use this program, specify the name
   of the source file and the destination file.
   For example, to copy a file called FIRST.TXT
   to a file called SECOND.TXT, use the following
   command line.

   java CopyFile FIRST.TXT SECOND.TXT
*/

import java.io.*;

class CopyFile {
  public static void main(String args[]) throws IOException
  {
    int i;
    FileInputStream fin = null;
    FileOutputStream fout = null;

    // First, confirm that both files have been specified.
    if(args.length != 2) {
      System.out.println("Usage: CopyFile from to");
      return;
```

```
    }

    // Copy a File.
    try {
      // Attempt to open the files.
      fin = new FileInputStream(args[0]);
      fout = new FileOutputStream(args[1]);

      do {
        i = fin.read();
        if(i != -1) fout.write(i);
      } while(i != -1);

    } catch(IOException e) {
      System.out.println("I/O Error: " + e);
    } finally {
      try {
        if(fin != null) fin.close();
      } catch(IOException e2) {
        System.out.println("Error Closing Input File");
      }
      try {
        if(fout != null) fout.close();
      } catch(IOException e2) {
        System.out.println("Error Closing Output File");
      }
    }
  }
}
```

In the program, notice that two separate **try** blocks are used when closing the files. This ensures that both files are closed, even if the call to **fin.close( )** throws an exception.

In general, notice that all potential I/O errors are handled in the preceding two programs by the use of exceptions. This differs from some computer languages that use error codes to report file errors. Not only do exceptions make file handling cleaner, but they also enable Java to easily differentiate the end-of-file condition from file errors when input is being performed.

Automatically Closing a File

In the preceding section, the example programs have made explicit calls to **close( )** to close a file once it is no longer needed. As mentioned, this is the way files were closed when using versions of Java prior to JDK 7. Although this approach is still valid and useful, JDK 7 added a feature that offers another way to manage resources, such as file streams, by automating the closing process. This feature, sometimes referred to as *automatic resource management*, or *ARM* for short, is based on an expanded version of the **try** statement. The principal advantage of automatic resource management is that it prevents situations in which a file (or other resource) is inadvertently not released after it is no longer needed. As explained, forgetting to close a file can result in memory leaks, and could lead to other problems.

Automatic resource management is based on an expanded form of the **try** statement. Here is its general form:

```
try (resource-specification) {
  // use the resource
}
```

Typically, *resource-specification* is a statement that declares and initializes a resource, such as a file stream. It consists of a variable declaration in which the variable is initialized with a reference to the object being managed. When the **try** block ends, the resource is automatically released. In the case of a file, this means that the file is automatically closed. (Thus, there is no need to call **close( )** explicitly.) Of course, this form of **try** can also include **catch** and **finally** clauses. This form of **try** is called the ***try*-*with*-*resources*** statement.

NOTE Beginning with JDK 9, it is also possible for the resource specification of the **try** to consist of a variable that has been declared and initialized earlier in the program. However, that variable must be *effectively final*, which means that it has not been assigned a new value after being given its initial value.

The **try**-with-resources statement can be used only with those resources that implement the **AutoCloseable** interface defined by **java.lang**. This interface defines the **close( )** method. **AutoCloseable** is inherited by the **Closeable** interface in **java.io**. Both interfaces are implemented by the stream classes. Thus, **try**-with-resources can be used when working with streams, including file streams.

As a first example of automatically closing a file, here is a reworked version

of the **ShowFile** program that uses it:

```
/* This version of the ShowFile program uses a try-with-resources
   statement to automatically close a file after it is no longer needed.
*/

import java.io.*;

class ShowFile {
  public static void main(String args[])
  {
    int i;

    // First, confirm that a filename has been specified.
    if(args.length != 1) {
      System.out.println("Usage: ShowFile filename");
      return;
    }

    // The following code uses a try-with-resources statement to open
    // a file and then automatically close it when the try block is left.
    try(FileInputStream fin = new FileInputStream(args[0])) {

      do {
        i = fin.read();
        if(i != -1) System.out.print((char) i);
      } while(i != -1);

    } catch(FileNotFoundException e) {
      System.out.println("File Not Found.");
    } catch(IOException e) {
      System.out.println("An I/O Error Occurred");
    }

  }
}
```

In the program, pay special attention to how the file is opened within the **try** statement:

```
try(FileInputStream fin = new FileInputStream(args[0])) {
```

Notice how the resource-specification portion of the **try** declares a

FileInputStream called **fin**, which is then assigned a reference to the file opened by its constructor. Thus, in this version of the program, the variable **fin** is local to the **try** block, being created when the **try** is entered. When the **try** is left, the stream associated with **fin** is automatically closed by an implicit call to **close( )**. You don't need to call **close( )** explicitly, which means that you can't forget to close the file. This is a key advantage of using **try**-with-resources.

It is important to understand that a resource declared in the **try** statement is implicitly **final**. This means that you can't assign to the resource after it has been created. Also, the scope of the resource is limited to the **try**-with-resources statement.

Before moving on it is useful to mention that beginning with JDK 10, you can use local variable type inference to specify the type of the resource declared in a **try**-with-resources statement. To do so, specify the type as **var**. When this is done, the type of the resource is inferred from its initializer. For example, the **try** statement in the preceding program can now be written like this:

```
try(var fin = new FileInputStream(args[0])) {
```

Here, **fin** is inferred to be of type **FileInputStream** because that is the type of its initializer. Because many readers will be working in Java environments that predate JDK 10, **try**-with-resource statements in the remainder of this book will not make use of type inference so that the code works for as many readers as possible. Of course, going forward, you should consider using type inference in your own code.

You can manage more than one resource within a single **try** statement. To do so, simply separate each resource specification with a semicolon. The following program shows an example. It reworks the **CopyFile** program shown earlier so that it uses a single **try**-with-resources statement to manage both **fin** and **fout**.

```
/* A version of CopyFile that uses try-with-resources.
   It demonstrates two resources (in this case files) being
   managed by a single try statement.
*/

import java.io.*;

class CopyFile {
  public static void main(String args[]) throws IOException
  {
    int i;

    // First, confirm that both files have been specified.
    if(args.length != 2) {
      System.out.println("Usage: CopyFile from to");
      return;
    }

    // Open and manage two files via the try statement.
    try (FileInputStream fin = new FileInputStream(args[0]);
         FileOutputStream fout = new FileOutputStream(args[1]))
    {

      do {
        i = fin.read();
        if(i != -1) fout.write(i);
      } while(i != -1);

    } catch(IOException e) {
      System.out.println("I/O Error: " + e);
    }
  }
}
```

In this program, notice how the input and output files are opened within the **try** block:

```
try (FileInputStream fin = new FileInputStream(args[0]);
     FileOutputStream fout = new FileOutputStream(args[1]))
{
  // ...
```

After this **try** block ends, both **fin** and **fout** will have been closed. If you compare this version of the program to the previous version, you will see that it is much shorter. The ability to streamline source code is a side-benefit of automatic resource management.

There is one other aspect to **try**-with-resources that needs to be mentioned. In general, when a **try** block executes, it is possible that an exception inside the **try** block will lead to another exception that occurs when the resource is closed in a **finally** clause. In the case of a "normal" **try** statement, the original exception is lost, being preempted by the second exception. However, when using **try**-with-resources, the second exception is *suppressed*. It is not, however, lost. Instead, it is added to the list of suppressed exceptions associated with the first exception. The list of suppressed exceptions can be obtained by using the **getSuppressed( )** method defined by **Throwable**.

Because of the benefits that the **try**-with-resources statement offers, it will be used by many, but not all, of the example programs in this edition of this book. Some of the examples will still use the traditional approach to closing a resource. There are several reasons for this. First, you may encounter legacy code that still relies on the traditional approach. It is important that all Java programmers be fully versed in, and comfortable with, the traditional approach when maintaining this older code. Second, it is possible that some programmers will continue to work in a pre-JDK 7 environment for a period of time. In such situations, the expanded form of **try** is not available. Finally, there may be cases in which explicitly closing a resource is more appropriate than the automated approach. For these reasons, some of the examples in this book will continue to use the traditional approach, explicitly calling **close( )**. In addition to illustrating the traditional technique, these examples can also be compiled and run by all readers in all environments.

REMEMBER A few examples in this book use the traditional approach to closing files as a means of illustrating this technique, which is widely used in legacy code. However, for new code, you will usually want to use the automated approach supported by the **try**-with-resources statement just described.

The transient and volatile Modifiers

Java defines two interesting type modifiers: **transient** and **volatile**. These modifiers are used to handle somewhat specialized situations.

When an instance variable is declared as **transient**, its value need not persist when an object is stored. For example:

```
class T {
  transient int a; // will not persist
  int b; // will persist
}
```

Here, if an object of type **T** is written to a persistent storage area, the contents of **a** would not be saved, but the contents of **b** would.

The **volatile** modifier tells the compiler that the variable modified by **volatile** can be changed unexpectedly by other parts of your program. One of these situations involves multithreaded programs. In a multithreaded program, sometimes two or more threads share the same variable. For efficiency considerations, each thread can keep its own, private copy of such a shared variable. The real (or *master*) copy of the variable is updated at various times, such as when a **synchronized** method is entered. While this approach works fine, it may be inefficient at times. In some cases, all that really matters is that the master copy of a variable always reflects its current state. To ensure this, simply specify the variable as **volatile**, which tells the compiler that it must always use the master copy of a **volatile** variable (or, at least, always keep any private copies up-to-date with the master copy, and vice versa). Also, accesses to the shared variable must be executed in the precise order indicated by the program.

Using instanceof

Sometimes, knowing the type of an object during run time is useful. For example, you might have one thread of execution that generates various types of objects, and another thread that processes these objects. In this situation, it might be useful for the processing thread to know the type of each object when it receives it. Another situation in which knowledge of an object’s type at run time is important involves casting. In Java, an invalid cast causes a run-time error. Many invalid casts can be caught at compile time. However, casts involving class hierarchies can produce invalid casts that can be detected only at run time. For example, a superclass called A can produce two subclasses, called B and C.

Thus, casting a B object into type A or casting a C object into type A is legal, but casting a B object into type C (or vice versa) isn't legal. Because an object of type A can refer to objects of either B or C, how can you know, at run time, what type of object is actually being referred to before attempting the cast to type C? It could be an object of type A, B, or C. If it is an object of type B, a run-time exception will be thrown. Java provides the run-time operator **instanceof** to answer this question.

The **instanceof** operator has this general form:

objref instanceof *type*

Here, *objref* is a reference to an instance of a class, and *type* is a class type. If *objref* is of the specified type or can be cast into the specified type, then the **instanceof** operator evaluates to **true**. Otherwise, its result is **false**. Thus, **instanceof** is the means by which your program can obtain run-time type information about an object.

The following program demonstrates **instanceof**:

```
// Demonstrate instanceof operator.
class A {
  int i, j;
}

class B {
  int i, j;
}

class C extends A {
  int k;
}

class D extends A {
  int k;
}

class InstanceOf {
  public static void main(String args[]) {
    A a = new A();
    B b = new B();
    C c = new C();
    D d = new D();
    if(a instanceof A)
      System.out.println("a is instance of A");
    if(b instanceof B)
      System.out.println("b is instance of B");
    if(c instanceof C)
      System.out.println("c is instance of C");
    if(c instanceof A)
      System.out.println("c can be cast to A");

    if(a instanceof C)
      System.out.println("a can be cast to C");

    System.out.println();

    // compare types of derived types
    A ob;

    ob = d; // A reference to d
    System.out.println("ob now refers to d");
    if(ob instanceof D)
      System.out.println("ob is instance of D");

    System.out.println();

    ob = c; // A reference to c
    System.out.println("ob now refers to c");
```

```
    if(ob instanceof D)
      System.out.println("ob can be cast to D");
    else
      System.out.println("ob cannot be cast to D");

    if(ob instanceof A)
      System.out.println("ob can be cast to A");

    System.out.println();

    // all objects can be cast to Object
    if(a instanceof Object)
      System.out.println("a may be cast to Object");
    if(b instanceof Object)
      System.out.println("b may be cast to Object");
    if(c instanceof Object)
      System.out.println("c may be cast to Object");
    if(d instanceof Object)
      System.out.println("d may be cast to Object");
  }
}
```

The output from this program is shown here:

```
a is instance of A
b is instance of B
c is instance of C
c can be cast to A

ob now refers to d
ob is instance of D

ob now refers to c
ob cannot be cast to D
ob can be cast to A

a may be cast to Object
b may be cast to Object
c may be cast to Object
d may be cast to Object
```

The **instanceof** operator isn't needed by most programs, because, generally, you know the type of object with which you are working. However, it can be very useful when you're writing generalized routines that operate on objects of a

complex class hierarchy.

strictfp

With the creation of Java 2 several years ago, the floating-point computation model was relaxed slightly. Specifically, the new model does not require the truncation of certain intermediate values that occur during a computation. This prevents overflow or underflow in some cases. By modifying a class, a method, or interface with **strictfp**, you ensure that floating-point calculations (and thus all truncations) take place precisely as they did in earlier versions of Java. When a class is modified by **strictfp**, all the methods in the class are also modified by **strictfp** automatically.

For example, the following fragment tells Java to use the original floating-point model for calculations in all methods defined within **MyClass**:

```
strictfp class MyClass { //...
```

Frankly, most programmers never need to use **strictfp**, because it affects only a very small class of problems.

Native Methods

Although it is rare, occasionally you may want to call a subroutine that is written in a language other than Java. Typically, such a subroutine exists as executable code for the CPU and environment in which you are working—that is, native code. For example, you may want to call a native code subroutine to achieve faster execution time. Or, you may want to use a specialized, third-party library, such as a statistical package. However, because Java programs are compiled to bytecode, which is then interpreted (or compiled on-the-fly) by the Java run-time system, it would seem impossible to call a native code subroutine from within your Java program. Fortunately, this conclusion is false. Java provides the **native** keyword, which is used to declare native code methods. Once declared, these methods can be called from inside your Java program just as you call any other Java method. The mechanism used to integrate native code with a Java program is called the *Java Native Interface (JNI)*.

To declare a native method, precede the method with the **native** modifier, but do not define any body for the method. For example:

```
public native int meth() ;
```

After you declare a native method, you must write the native method and follow a rather complex series of steps to link it with your Java code. Consult the Java documentation for current details.

Using assert

Another interesting keyword is **assert**. It is used during program development to create an *assertion*, which is a condition that should be true during the execution of the program. For example, you might have a method that should always return a positive integer value. You might test this by asserting that the return value is greater than zero using an **assert** statement. At run time, if the condition is true, no other action takes place. However, if the condition is false, then an **AssertionError** is thrown. Assertions are often used during testing to verify that some expected condition is actually met. They are not usually used for released code.

The **assert** keyword has two forms. The first is shown here:

assert *condition*;

Here, *condition* is an expression that must evaluate to a Boolean result. If the result is true, then the assertion is true and no other action takes place. If the condition is false, then the assertion fails and a default **AssertionError** object is thrown.

The second form of **assert** is shown here:

assert *condition: expr* ;

In this version, *expr* is a value that is passed to the **AssertionError** constructor. This value is converted to its string format and displayed if an assertion fails. Typically, you will specify a string for *expr*, but any non-**void** expression is allowed as long as it defines a reasonable string conversion.

Here is an example that uses **assert**. It verifies that the return value of **getnum( )** is positive.

```
// Demonstrate assert.
class AssertDemo {
  static int val = 3;

  // Return an integer.
  static int getnum() {
    return val--;
  }

  public static void main(String args[])
  {
    int n;

    for(int i=0; i < 10; i++) {
      n = getnum();

      assert n > 0; // will fail when n is 0

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

To enable assertion checking at run time, you must specify the **-ea** option. For example, to enable assertions for **AssertDemo**, execute it using this line:

```
java -ea AssertDemo
```

After compiling and running as just described, the program creates the following output:

```
n is 3
n is 2
n is 1
Exception in thread "main" java.lang.AssertionError
        at AssertDemo.main(AssertDemo.java:17)
```

In **main( )**, repeated calls are made to the method **getnum( )**, which returns an integer value. The return value of **getnum( )** is assigned to **n** and then tested using this **assert** statement:

```
assert n > 0; // will fail when n is 0
```

This statement will fail when **n** equals 0, which it will after the fourth call. When this happens, an exception is thrown.

As explained, you can specify the message displayed when an assertion fails. For example, if you substitute

```
assert n > 0 : "n is not positive!";
```

for the assertion in the preceding program, then the following output will be generated:

```
n is 3
n is 2
n is 1
Exception in thread "main" java.lang.AssertionError: n is not
positive!
        at AssertDemo.main(AssertDemo.java:17)
```

One important point to understand about assertions is that you must not rely on them to perform any action actually required by the program. The reason is that normally, released code will be run with assertions disabled. For example, consider this variation of the preceding program:

```
// A poor way to use assert!!!
class AssertDemo {
  // get a random number generator
  static int val = 3;

  // Return an integer.
  static int getnum() {
    return val--;
  }

  public static void main(String args[])
  {
    int n = 0;

    for(int i=0; i < 10; i++) {

      assert (n = getnum()) > 0; // This is not a good idea!

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

In this version of the program, the call to **getnum( )** is moved inside the **assert** statement. Although this works fine if assertions are enabled, it will cause a malfunction when assertions are disabled, because the call to **getnum( )** will never be executed! In fact, **n** must now be initialized, because the compiler will recognize that it might not be assigned a value by the **assert** statement.

Assertions can be quite useful because they streamline the type of error checking that is common during development. For example, prior to **assert**, if you wanted to verify that **n** was positive in the preceding program, you had to use a sequence of code similar to this:

```
if(n < 0) {
   System.out.println("n is negative!");
   return; // or throw an exception
}
```

With **assert**, you need only one line of code. Furthermore, you don’t have to

remove the **assert** statements from your released code.

Assertion Enabling and Disabling Options

When executing code, you can disable all assertions by using the **-da** option. You can enable or disable a specific package (and all of its subpackages) by specifying its name followed by three periods after the **-ea** or **-da** option. For example, to enable assertions in a package called **MyPack**, use

```
-ea:MyPack...
```

To disable assertions in **MyPack**, use

```
-da:MyPack...
```

You can also specify a class with the **-ea** or **-da** option. For example, this enables **AssertDemo** individually:

```
-ea:AssertDemo
```

Static Import

Java includes a feature called *static import* that expands the capabilities of the **import** keyword. By following **import** with the keyword **static**, an **import** statement can be used to import the static members of a class or interface. When using static import, it is possible to refer to static members directly by their names, without having to qualify them with the name of their class. This simplifies and shortens the syntax required to use a static member.

To understand the usefulness of static import, let's begin with an example that does *not* use it. The following program computes the hypotenuse of a right triangle. It uses two static methods from Java's built-in math class **Math**, which is part of **java.lang**. The first is **Math.pow( )**, which returns a value raised to a specified power. The second is **Math.sqrt( )**, which returns the square root of its argument.

```
// Compute the hypotenuse of a right triangle.
class Hypot {
  public static void main(String args[]) {
    double side1, side2;
    double hypot;
    side1 = 3.0;
    side2 = 4.0;

    // Notice how sqrt() and pow() must be qualified by
    // their class name, which is Math.
    hypot = Math.sqrt(Math.pow(side1, 2) +
                      Math.pow(side2, 2));

    System.out.println("Given sides of lengths " +
                       side1 + " and " + side2 +
                       " the hypotenuse is " +
                       hypot);
  }
}
```

Because **pow( )** and **sqrt( )** are static methods, they must be called through the use of their class' name, **Math**. This results in a somewhat unwieldy hypotenuse calculation:

```
hypot = Math.sqrt(Math.pow(side1, 2) +
                  Math.pow(side2, 2));
```

As this simple example illustrates, having to specify the class name each time **pow( )** or **sqrt( )** (or any of Java's other math methods, such as **sin( )**, **cos( )**, and **tan( )**) is used can grow tedious.

You can eliminate the tedium of specifying the class name through the use of static import, as shown in the following version of the preceding program:

```
// Use static import to bring sqrt() and pow() into view.
import static java.lang.Math.sqrt;
import static java.lang.Math.pow;

// Compute the hypotenuse of a right triangle.
class Hypot {
  public static void main(String args[]) {
    double side1, side2;
    double hypot;

    side1 = 3.0;
    side2 = 4.0;

    // Here, sqrt() and pow() can be called by themselves,
    // without their class name.
    hypot = sqrt(pow(side1, 2) + pow(side2, 2));

    System.out.println("Given sides of lengths " +
                       side1 + " and " + side2 +
                       " the hypotenuse is " +
                       hypot);
  }
}
```

In this version, the names **sqrt** and **pow** are brought into view by these static import statements:

```
import static java.lang.Math.sqrt;
import static java.lang.Math.pow;
```

After these statements, it is no longer necessary to qualify **sqrt( )** or **pow( )** with their class name. Therefore, the hypotenuse calculation can more conveniently be specified, as shown here:

```
hypot = sqrt(pow(side1, 2) + pow(side2, 2));
```

As you can see, this form is considerably more readable.

There are two general forms of the **import static** statement. The first, which is used by the preceding example, brings into view a single name. Its general form is shown here:

import static *pkg.type-name.static-member-name* ;

Here, *type-name* is the name of a class or interface that contains the desired static member. Its full package name is specified by *pkg*. The name of the member is specified by *static-member-name*.

The second form of static import imports all static members of a given class or interface. Its general form is shown here:

import static *pkg.type-name*.*;

If you will be using many static methods or fields defined by a class, then this form lets you bring them into view without having to specify each individually. Therefore, the preceding program could have used this single **import** statement to bring both **pow( )** and **sqrt( )** (and *all other* static members of **Math**) into view:

```
import static java.lang.Math.*;
```

Of course, static import is not limited just to the **Math** class or just to methods. For example, this brings the static field **System.out** into view:

```
import static java.lang.System.out;
```

After this statement, you can output to the console without having to qualify **out** with **System**, as shown here:

```
out.println("After importing System.out, you can use out
directly.");
```

Whether importing **System.out** as just shown is a good idea is subject to debate. Although it does shorten the statement, it is no longer instantly clear to anyone reading the program that the **out** being referred to is **System.out**.

One other point: in addition to importing the static members of classes and interfaces defined by the Java API, you can also use static import to import the static members of classes and interfaces that you create.

As convenient as static import can be, it is important not to abuse it. Remember, the reason that Java organizes its libraries into packages is to avoid namespace collisions. When you import static members, you are bringing those members into the current namespace. Thus, you are increasing the potential for namespace conflicts and inadvertent name hiding. If you are using a static

member once or twice in the program, it's best not to import it. Also, some static names, such as **System.out**, are so recognizable that you might not want to import them. Static import is designed for those situations in which you are using a static member repeatedly, such as when performing a series of mathematical computations. In essence, you should use, but not abuse, this feature.

Invoking Overloaded Constructors Through this( )

When working with overloaded constructors, it is sometimes useful for one constructor to invoke another. In Java, this is accomplished by using another form of the **this** keyword. The general form is shown here:

this(*arg-list*)

When **this( )** is executed, the overloaded constructor that matches the parameter list specified by *arg-list* is executed first. Then, if there are any statements inside the original constructor, they are executed. The call to **this( )** must be the first statement within the constructor.

To understand how **this( )** can be used, let's work through a short example. First, consider the following class that *does not* use **this( )**:

```
class MyClass {
  int a;
  int b;

  // initialize a and b individually
  MyClass(int i, int j) {
    a = i;
    b = j;
  }

  // initialize a and b to the same value
  MyClass(int i) {
    a = i;
    b = i;
  }

  // give a and b default values of 0
  MyClass( ) {
    a = 0;
    b = 0;
  }
}
```

This class contains three constructors, each of which initializes the values of **a** and **b**. The first is passed individual values for **a** and **b**. The second is passed just one value, which is assigned to both **a** and **b**. The third gives **a** and **b** default values of zero.

By using **this( )**, it is possible to rewrite **MyClass** as shown here:

```
class MyClass {
  int a;
  int b;

  // initialize a and b individually
  MyClass(int i, int j) {
    a = i;
    b = j;
  }

  // initialize a and b to the same value
  MyClass(int i) {
    this(i, i); // invokes MyClass(i, i)
  }

  // give a and b default values of 0
  MyClass( ) {
    this(0); // invokes MyClass(0)
  }
}
```

In this version of **MyClass**, the only constructor that actually assigns values to the **a** and **b** fields is **MyClass(int, int)**. The other two constructors simply invoke that constructor (either directly or indirectly) through **this( )**. For example, consider what happens when this statement executes:

```
MyClass mc = new MyClass(8);
```

The call to **MyClass(8)** causes **this(8, 8)** to be executed, which translates into a call to **MyClass(8, 8)**, because this is the version of the **MyClass** constructor whose parameter list matches the arguments passed via **this( )**. Now, consider the following statement, which uses the default constructor:

```
MyClass mc2 = new MyClass();
```

In this case, **this(0)** is called. This causes **MyClass(0)** to be invoked because it is the constructor with the matching parameter list. Of course, **MyClass(0)** then calls **MyClass(0,0)** as just described.

One reason why invoking overloaded constructors through **this( )** can be useful is that it can prevent the unnecessary duplication of code. In many cases,

reducing duplicate code decreases the time it takes to load your class because often the object code is smaller. This is especially important for programs delivered via the Internet in which load times are an issue. Using **this( )** can also help structure your code when constructors contain a large amount of duplicate code.

However, you need to be careful. Constructors that call **this( )** will execute a bit slower than those that contain all of their initialization code inline. This is because the call and return mechanism used when the second constructor is invoked adds overhead. If your class will be used to create only a handful of objects, or if the constructors in the class that call **this( )** will be seldom used, then this decrease in run-time performance is probably insignificant. However, if your class will be used to create a large number of objects (on the order of thousands) during program execution, then the negative impact of the increased overhead could be meaningful. Because object creation affects all users of your class, there will be cases in which you must carefully weigh the benefits of faster load time against the increased time it takes to create an object.

Here is another consideration: for very short constructors, such as those used by **MyClass**, there is often little difference in the size of the object code whether **this( )** is used or not. (Actually, there are cases in which no reduction in the size of the object code is achieved.) This is because the bytecode that sets up and returns from the call to **this( )** adds instructions to the object file. Therefore, in these types of situations, even though duplicate code is eliminated, using **this( )** will not obtain significant savings in terms of load time. However, the added cost in terms of overhead to each object's construction will still be incurred. Therefore, **this( )** is most applicable to constructors that contain large amounts of initialization code, not those that simply set the value of a handful of fields.

There are two restrictions you need to keep in mind when using **this( )**. First, you cannot use any instance variable of the constructor's class in a call to **this( )**. Second, you cannot use **super( )** and **this( )** in the same constructor because each must be the first statement in the constructor.

A Word About Compact API Profiles

JDK 8 added a feature that organizes subsets of the API library into what are called *compact profiles*. These are called **compact1**, **compact2**, and **compact3**. Each profile contains a subset of the library. Furthermore, **compact2** includes all of **compact1**, and **compact3** includes all of **compact2**. Thus, each profile builds on the previous one. The advantage of the compact profiles is that an application

that does not require the full library need not download it. Using a compact profile reduces the size of the library, thus enabling some types of Java applications to run on devices that could not otherwise support the entire Java API. The use of a compact profile can also reduce the time it takes to load a program. The JDK 8 API documentation indicates to which (if any) profile each API element belongs. It is important to emphasize that the modules feature added by JDK 9 supersedes compact profiles.

CHAPTER

14

Generics

Since the original 1.0 release in 1995, many new features have been added to Java. One that has had a profound and long-lasting impact is *generics*. Introduced by JDK 5, generics changed Java in two important ways. First, it added a new syntactical element to the language. Second, it caused changes to many of the classes and methods in the core API. Today, generics are an integral part of Java programming, and a solid understanding of this important feature is required. It is examined here in detail.

Through the use of generics, it is possible to create classes, interfaces, and methods that will work in a type-safe manner with various kinds of data. Many algorithms are logically the same no matter what type of data they are being applied to. For example, the mechanism that supports a stack is the same whether that stack is storing items of type **Integer**, **String**, **Object**, or **Thread**. With generics, you can define an algorithm once, independently of any specific type of data, and then apply that algorithm to a wide variety of data types without any additional effort. The expressive power generics added to the language fundamentally changed the way that Java code is written.

Perhaps the one feature of Java that has been most significantly affected by generics is the *Collections Framework*. The Collections Framework is part of the Java API and is described in detail in Chapter 19, but a brief mention is useful now. A *collection* is a group of objects. The Collections Framework defines several classes, such as lists and maps, that manage collections. The collection classes have always been able to work with any type of object. The benefit that generics added is that the collection classes can now be used with complete type safety. Thus, in addition to being a powerful language element on its own, generics also enabled an existing feature to be substantially improved. This is another reason why generics were such an important addition to Java.

This chapter describes the syntax, theory, and use of generics. It also shows how generics provide type safety for some previously difficult cases. Once you have completed this chapter, you will want to examine Chapter 19, which covers the Collections Framework. There you will find many examples of generics at work.

What Are Generics?

At its core, the term *generics* means *parameterized types*. Parameterized types are important because they enable you to create classes, interfaces, and methods in which the type of data upon which they operate is specified as a parameter. Using generics, it is possible to create a single class, for example, that automatically works with different types of data. A class, interface, or method that operates on a parameterized type is called *generic*, as in *generic class* or *generic method*.

It is important to understand that Java has always given you the ability to create generalized classes, interfaces, and methods by operating through references of type **Object**. Because **Object** is the superclass of all other classes, an **Object** reference can refer to any type object. Thus, in pre-generics code, generalized classes, interfaces, and methods used **Object** references to operate on various types of objects. The problem was that they could not do so with type safety.

Generics added the type safety that was lacking. They also streamlined the process, because it is no longer necessary to explicitly employ casts to translate between **Object** and the type of data that is actually being operated upon. With generics, all casts are automatic and implicit. Thus, generics expanded your ability to reuse code and let you do so safely and easily.

CAUTION *A Warning to C++ Programmers:* Although generics are similar to templates in C++, they are not the same. There are some fundamental differences between the two approaches to generic types. If you have a background in C++, it is important not to jump to conclusions about how generics work in Java.

A Simple Generics Example

Let’s begin with a simple example of a generic class. The following program defines two classes. The first is the generic class **Gen**, and the second is **GenDemo**, which uses **Gen**.

```
// A simple generic class.
// Here, T is a type parameter that
// will be replaced by a real type
// when an object of type Gen is created.
class Gen<T> {
  T ob; // declare an object of type T

  // Pass the constructor a reference to
  // an object of type T.
  Gen(T o) {
    ob = o;
  }

  // Return ob.
  T getob() {
    return ob;
  }

  // Show type of T.
```

```
  void showType() {
    System.out.println("Type of T is " +
                       ob.getClass().getName());
  }
}

// Demonstrate the generic class.
class GenDemo {
  public static void main(String args[]) {
    // Create a Gen reference for Integers.
    Gen<Integer> iOb;

    // Create a Gen<Integer> object and assign its
    // reference to iOb. Notice the use of autoboxing
    // to encapsulate the value 88 within an Integer object.
    iOb = new Gen<Integer>(88);

    // Show the type of data used by iOb.
    iOb.showType();

    // Get the value in iOb. Notice that
    // no cast is needed.
    int v = iOb.getob();
    System.out.println("value: " + v);

    System.out.println();

    // Create a Gen object for Strings.
    Gen<String> strOb = new Gen<String> ("Generics Test");

    // Show the type of data used by strOb.
    strOb.showType();

    // Get the value of strOb. Again, notice
    // that no cast is needed.
    String str = strOb.getob();
    System.out.println("value: " + str);
  }
}
```

The output produced by the program is shown here:

```
Type of T is java.lang.Integer
value: 88

Type of T is java.lang.String
value: Generics Test
```

Let's examine this program carefully.

First, notice how **Gen** is declared by the following line:

```
class Gen<T> {
```

Here, **T** is the name of a *type parameter*. This name is used as a placeholder for the actual type that will be passed to **Gen** when an object is created. Thus, **T** is used within **Gen** whenever the type parameter is needed. Notice that **T** is contained within < >. This syntax can be generalized. Whenever a type parameter is being declared, it is specified within angle brackets. Because **Gen** uses a type parameter, **Gen** is a generic class, which is also called a *parameterized type*.

In the declaration of **Gen**, there is no special significance to the name **T**. Any valid identifier could have been used, but **T** is traditional. Furthermore, it is recommended that type parameter names be single-character capital letters. Other commonly used type parameter names are **V** and **E**. One other point about type parameter names: Beginning with JDK 10, you cannot use **var** as the name of a type parameter.

Next, **T** is used to declare an object called **ob**, as shown here:

```
T ob; // declare an object of type T
```

As explained, **T** is a placeholder for the actual type that will be specified when a **Gen** object is created. Thus, **ob** will be an object of the type passed to **T**. For example, if type **String** is passed to **T**, then in that instance, **ob** will be of type **String**.

Now consider **Gen**'s constructor:

```
Gen(T o) {
  ob = o;
}
```

Notice that its parameter, **o**, is of type **T**. This means that the actual type of **o** is

determined by the type passed to **T** when a **Gen** object is created. Also, because both the parameter **o** and the member variable **ob** are of type **T**, they will both be of the same actual type when a **Gen** object is created.

The type parameter **T** can also be used to specify the return type of a method, as is the case with the **getob( )** method, shown here:

```
T getob() {
  return ob;
}
```

Because **ob** is also of type **T**, its type is compatible with the return type specified by **getob( )**.

The **showType( )** method displays the type of **T** by calling **getName( )** on the **Class** object returned by the call to **getClass( )** on **ob**. The **getClass( )** method is defined by **Object** and is thus a member of all class types. It returns a **Class** object that corresponds to the type of the class of the object on which it is called. **Class** defines the **getName( )** method, which returns a string representation of the class name.

The **GenDemo** class demonstrates the generic **Gen** class. It first creates a version of **Gen** for integers, as shown here:

```
Gen<Integer> iOb;
```

Look closely at this declaration. First, notice that the type **Integer** is specified within the angle brackets after **Gen**. In this case, **Integer** is a *type argument* that is passed to **Gen**'s type parameter, **T**. This effectively creates a version of **Gen** in which all references to **T** are translated into references to **Integer**. Thus, for this declaration, **ob** is of type **Integer**, and the return type of **getob( )** is of type **Integer**.

Before moving on, it's necessary to state that the Java compiler does not actually create different versions of **Gen**, or of any other generic class. Although it's helpful to think in these terms, it is not what actually happens. Instead, the compiler removes all generic type information, substituting the necessary casts, to make your code *behave as if* a specific version of **Gen** were created. Thus, there is really only one version of **Gen** that actually exists in your program. The process of removing generic type information is called *erasure*, and we will return to this topic later in this chapter.

The next line assigns to **iOb** a reference to an instance of an **Integer** version of the **Gen** class:

```
iOb = new Gen<Integer>(88);
```

Notice that when the **Gen** constructor is called, the type argument **Integer** is also specified. This is because the type of the object (in this case **iOb**) to which the reference is being assigned is of type **Gen<Integer>**. Thus, the reference returned by **new** must also be of type **Gen<Integer>**. If it isn't, a compile-time error will result. For example, the following assignment will cause a compile-time error:

```
iOb = new Gen<Double>(88.0); // Error!
```

Because **iOb** is of type **Gen<Integer>**, it can't be used to refer to an object of **Gen<Double>**. This type checking is one of the main benefits of generics because it ensures type safety.

NOTE As you will see later in this chapter, it is possible to shorten the syntax used to create an instance of a generic class. In the interest of clarity, we will use the full syntax at this time.

As the comments in the program state, the assignment

```
iOb = new Gen<Integer>(88);
```

makes use of autoboxing to encapsulate the value 88, which is an **int**, into an **Integer**. This works because **Gen<Integer>** creates a constructor that takes an **Integer** argument. Because an **Integer** is expected, Java will automatically box 88 inside one. Of course, the assignment could also have been written explicitly, like this:

```
iOb = new Gen<Integer>(Integer.valueOf(88));
```

However, there would be no benefit to using this version.

The program then displays the type of **ob** within **iOb**, which is **Integer**. Next, the program obtains the value of **ob** by use of the following line:

```
int v = iOb.getob();
```

Because the return type of **getob( )** is **T**, which was replaced by **Integer** when **iOb** was declared, the return type of **getob( )** is also **Integer**, which unboxes into **int** when assigned to **v** (which is an **int**). Thus, there is no need to cast the return type of **getob( )** to **Integer**. Of course, it's not necessary to use the auto-unboxing feature. The preceding line could have been written like this, too:

```
int v = iOb.getob().intValue();
```

However, the auto-unboxing feature makes the code more compact.

Next, **GenDemo** declares an object of type **Gen<String>**:

```
Gen<String> strOb = new Gen<String>("Generics Test");
```

Because the type argument is **String**, **String** is substituted for **T** inside **Gen**. This creates (conceptually) a **String** version of **Gen**, as the remaining lines in the program demonstrate.

Generics Work Only with Reference Types

When declaring an instance of a generic type, the type argument passed to the type parameter must be a reference type. You cannot use a primitive type, such as **int** or **char**. For example, with **Gen**, it is possible to pass any class type to **T**, but you cannot pass a primitive type to a type parameter. Therefore, the following declaration is illegal:

```
Gen<int> intOb = new Gen<int>(53); // Error, can't use primitive
type
```

Of course, not being able to specify a primitive type is not a serious restriction because you can use the type wrappers (as the preceding example did) to encapsulate a primitive type. Further, Java's autoboxing and auto-unboxing mechanism makes the use of the type wrapper transparent.

Generic Types Differ Based on Their Type Arguments

A key point to understand about generic types is that a reference of one specific version of a generic type is not type compatible with another version of the same generic type. For example, assuming the program just shown, the following line of code is in error and will not compile:

```
iOb = strOb; // Wrong!
```

Even though both **iOb** and **strOb** are of type **Gen<T>**, they are references to different types because their type arguments differ. This is part of the way that generics add type safety and prevent errors.

How Generics Improve Type Safety

At this point, you might be asking yourself the following question: Given that the same functionality found in the generic **Gen** class can be achieved without generics, by simply specifying **Object** as the data type and employing the proper casts, what is the benefit of making **Gen** generic? The answer is that generics automatically ensure the type safety of all operations involving **Gen**. In the process, they eliminate the need for you to enter casts and to type-check code by hand.

To understand the benefits of generics, first consider the following program that creates a non-generic equivalent of **Gen**:

```
// NonGen is functionally equivalent to Gen
// but does not use generics.
class NonGen {
  Object ob; // ob is now of type Object

  // Pass the constructor a reference to
  // an object of type Object
  NonGen(Object o) {
    ob = o;
  }

  // Return type Object.
  Object getob() {
    return ob;
  }

  // Show type of ob.
  void showType() {
    System.out.println("Type of ob is " +
                       ob.getClass().getName());
  }
}

// Demonstrate the non-generic class.
class NonGenDemo {
  public static void main(String args[]) {
    NonGen iOb;

    // Create NonGen Object and store
    // an Integer in it. Autoboxing still occurs.
    iOb = new NonGen(88);

    // Show the type of data used by iOb.
    iOb.showType();

    // Get the value of iOb.
    // This time, a cast is necessary.
    int v = (Integer) iOb.getob();
    System.out.println("value: " + v);

    System.out.println();

    // Create another NonGen object and
    // store a String in it.
    NonGen strOb = new NonGen("Non-Generics Test");

    // Show the type of data used by strOb.
    strOb.showType();

    // Get the value of strOb.
    // Again, notice that a cast is necessary.
```

```
    String str = (String) strOb.getob();
    System.out.println("value: " + str);

    // This compiles, but is conceptually wrong!
    iOb = strOb;
    v = (Integer) iOb.getob(); // run-time error!
  }
}
```

There are several things of interest in this version. First, notice that **NonGen** replaces all uses of **T** with **Object**. This makes **NonGen** able to store any type of object, as can the generic version. However, it also prevents the Java compiler from having any real knowledge about the type of data actually stored in **NonGen**, which is bad for two reasons. First, explicit casts must be employed to retrieve the stored data. Second, many kinds of type mismatch errors cannot be found until run time. Let's look closely at each problem.

Notice this line:

```
int v = (Integer) iOb.getob();
```

Because the return type of **getob( )** is **Object**, the cast to **Integer** is necessary to enable that value to be auto-unboxed and stored in **v**. If you remove the cast, the program will not compile. With the generic version, this cast was implicit. In the non-generic version, the cast must be explicit. This is not only an inconvenience, but also a potential source of error.

Now, consider the following sequence from near the end of the program:

```
// This compiles, but is conceptually wrong!
iOb = strOb;
v = (Integer) iOb.getob(); // run-time error!
```

Here, **strOb** is assigned to **iOb**. However, **strOb** refers to an object that contains a string, not an integer. This assignment is syntactically valid because all **NonGen** references are the same, and any **NonGen** reference can refer to any other **NonGen** object. However, the statement is semantically wrong, as the next line shows. Here, the return type of **getob( )** is cast to **Integer**, and then an attempt is made to assign this value to **v**. The trouble is that **iOb** now refers to an object that stores a **String**, not an **Integer**. Unfortunately, without the use of generics, the Java compiler has no way to know this. Instead, a run-time

exception occurs when the cast to **Integer** is attempted. As you know, it is extremely bad to have run-time exceptions occur in your code!

The preceding sequence can't occur when generics are used. If this sequence were attempted in the generic version of the program, the compiler would catch it and report an error, thus preventing a serious bug that results in a run-time exception. The ability to create type-safe code in which type-mismatch errors are caught at compile time is a key advantage of generics. Although using **Object** references to create "generic" code has always been possible, that code was not type safe, and its misuse could result in run-time exceptions. Generics prevent this from occurring. In essence, through generics, run-time errors are converted into compile-time errors. This is a major advantage.

A Generic Class with Two Type Parameters

You can declare more than one type parameter in a generic type. To specify two or more type parameters, simply use a comma-separated list. For example, the following **TwoGen** class is a variation of the **Gen** class that has two type parameters:

```
// A simple generic class with two type
// parameters: T and V.
class TwoGen<T, V> {
  T ob1;
  V ob2;

  // Pass the constructor a reference to
  // an object of type T and an object of type V.
  TwoGen(T o1, V o2) {
    ob1 = o1;
    ob2 = o2;
  }

  // Show types of T and V.
  void showTypes() {
    System.out.println("Type of T is " +
                       ob1.getClass().getName());

    System.out.println("Type of V is " +
                       ob2.getClass().getName());
  }

  T getob1() {
    return ob1;
  }

  V getob2() {
    return ob2;
  }
}

// Demonstrate TwoGen.
class SimpGen {
  public static void main(String args[]) {

    TwoGen<Integer, String> tgObj =
      new TwoGen<Integer, String>(88, "Generics");

    // Show the types.
    tgObj.showTypes();

    // Obtain and show values.
    int v = tgObj.getob1();
    System.out.println("value: " + v);

    String str = tgObj.getob2();
    System.out.println("value: " + str);
  }
}
```

The output from this program is shown here:

```
Type of T is java.lang.Integer
Type of V is java.lang.String
value: 88
value: Generics
```

Notice how **TwoGen** is declared:

```
class TwoGen<T, V> {
```

It specifies two type parameters: **T** and **V**, separated by a comma. Because it has two type parameters, two type arguments must be passed to **TwoGen** when an object is created, as shown next:

```
TwoGen<Integer, String> tgObj =
  new TwoGen<Integer, String>(88, "Generics");
```

In this case, **Integer** is substituted for **T**, and **String** is substituted for **V**.

Although the two type arguments differ in this example, it is possible for both types to be the same. For example, the following line of code is valid:

```
TwoGen<String, String> x = new TwoGen<String, String> ("A", "B");
```

In this case, both **T** and **V** would be of type **String**. Of course, if the type arguments were always the same, then two type parameters would be unnecessary.

The General Form of a Generic Class

The generics syntax shown in the preceding examples can be generalized. Here is the syntax for declaring a generic class:

class *class-name*<*type-param-list* > { // …

Here is the full syntax for declaring a reference to a generic class and instance creation:

class-name<*type-arg-list* > *var-name* =
new *class-name*<*type-arg-list* >(*cons-arg-list*);

Bounded Types

In the preceding examples, the type parameters could be replaced by any class type. This is fine for many purposes, but sometimes it is useful to limit the types that can be passed to a type parameter. For example, assume that you want to create a generic class that contains a method that returns the average of an array of numbers. Furthermore, you want to use the class to obtain the average of an array of any type of number, including integers, **float**s, and **double**s. Thus, you want to specify the type of the numbers generically, using a type parameter. To create such a class, you might try something like this:

```
// Stats attempts (unsuccessfully) to
// create a generic class that can compute
// the average of an array of numbers of
// any given type.
//
// The class contains an error!
class Stats<T> {
  T[] nums; // nums is an array of type T

  // Pass the constructor a reference to
  // an array of type T.
  Stats(T[] o) {
    nums = o;
  }

  // Return type double in all cases.
  double average() {
    double sum = 0.0;
    for(int i=0; i < nums.length; i++)
      sum += nums[i].doubleValue(); // Error!!!

    return sum / nums.length;
  }
}
```

In **Stats**, the **average( )** method attempts to obtain the **double** version of each number in the **nums** array by calling **doubleValue( )**. Because all numeric classes, such as **Integer** and **Double**, are subclasses of **Number**, and **Number**

defines the **doubleValue( )** method, this method is available to all numeric wrapper classes. The trouble is that the compiler has no way to know that you are intending to create **Stats** objects using only numeric types. Thus, when you try to compile **Stats**, an error is reported that indicates that the **doubleValue( )** method is unknown. To solve this problem, you need some way to tell the compiler that you intend to pass only numeric types to **T**. Furthermore, you need some way to *ensure* that *only* numeric types are actually passed.

To handle such situations, Java provides *bounded types*. When specifying a type parameter, you can create an upper bound that declares the superclass from which all type arguments must be derived. This is accomplished through the use of an **extends** clause when specifying the type parameter, as shown here:

<*T* extends *superclass*>

This specifies that *T* can only be replaced by *superclass*, or subclasses of *superclass*. Thus, *superclass* defines an inclusive, upper limit.

You can use an upper bound to fix the **Stats** class shown earlier by specifying **Number** as an upper bound, as shown here:

```
// In this version of Stats, the type argument for
// T must be either Number, or a class derived
// from Number.
class Stats<T extends Number> {
  T[] nums; // array of Number or subclass
```

```
  // Pass the constructor a reference to
  // an array of type Number or subclass.
  Stats(T[] o) {
    nums = o;
  }

  // Return type double in all cases.
  double average() {
    double sum = 0.0;

    for(int i=0; i < nums.length; i++)
      sum += nums[i].doubleValue();

    return sum / nums.length;
  }
}

// Demonstrate Stats.
class BoundsDemo {
  public static void main(String args[]) {

    Integer inums[] = { 1, 2, 3, 4, 5 };
    Stats<Integer> iob = new Stats<Integer>(inums);
    double v = iob.average();
    System.out.println("iob average is " + v);

    Double dnums[] = { 1.1, 2.2, 3.3, 4.4, 5.5 };
    Stats<Double> dob = new Stats<Double>(dnums);
    double w = dob.average();
    System.out.println("dob average is " + w);

    // This won't compile because String is not a
    // subclass of Number.
//    String strs[] = { "1", "2", "3", "4", "5" };
//    Stats<String> strob = new Stats<String>(strs);

//    double x = strob.average();
//    System.out.println("strob average is " + v);

  }
}
```

The output is shown here:

```
Average is 3.0
Average is 3.3
```

Notice how **Stats** is now declared by this line:

```
class Stats<T extends Number> {
```

Because the type **T** is now bounded by **Number**, the Java compiler knows that all objects of type **T** can call **doubleValue( )** because it is a method declared by **Number**. This is, by itself, a major advantage. However, as an added bonus, the bounding of **T** also prevents nonnumeric **Stats** objects from being created. For example, if you try removing the comments from the lines at the end of the program, and then try recompiling, you will receive compile-time errors because **String** is not a subclass of **Number**.

In addition to using a class type as a bound, you can also use an interface type. In fact, you can specify multiple interfaces as bounds. Furthermore, a bound can include both a class type and one or more interfaces. In this case, the class type must be specified first. When a bound includes an interface type, only type arguments that implement that interface are legal. When specifying a bound that has a class and an interface, or multiple interfaces, use the **&** operator to connect them. This creates an *intersection type*. For example,

```
class Gen<T extends MyClass & MyInterface> { // ...
```

Here, **T** is bounded by a class called **MyClass** and an interface called **MyInterface**. Thus, any type argument passed to **T** must be a subclass of **MyClass** and implement **MyInterface**. As a point of interest, you can also use a type intersection in a cast.

Using Wildcard Arguments

As useful as type safety is, sometimes it can get in the way of perfectly acceptable constructs. For example, given the **Stats** class shown at the end of the preceding section, assume that you want to add a method called **sameAvg( )** that determines if two **Stats** objects contain arrays that yield the same average, no matter what type of numeric data each object holds. For example, if one object contains the **double** values 1.0, 2.0, and 3.0, and the other object contains the

integer values 2, 1, and 3, then the averages will be the same. One way to implement **sameAvg( )** is to pass it a **Stats** argument, and then compare the average of that argument against the invoking object, returning true only if the averages are the same. For example, you want to be able to call **sameAvg( )**, as shown here:

```
Integer inums[] = { 1, 2, 3, 4, 5 };
Double dnums[] = { 1.1, 2.2, 3.3, 4.4, 5.5 };

Stats<Integer> iob = new Stats<Integer>(inums);
Stats<Double> dob = new Stats<Double>(dnums);

if(iob.sameAvg(dob))
  System.out.println("Averages are the same.");
else
  System.out.println("Averages differ.");
```

At first, creating **sameAvg( )** seems like an easy problem. Because **Stats** is generic and its **average( )** method can work on any type of **Stats** object, it seems that creating **sameAvg( )** would be straightforward. Unfortunately, trouble starts as soon as you try to declare a parameter of type **Stats**. Because **Stats** is a parameterized type, what do you specify for **Stats**' type parameter when you declare a parameter of that type?

At first, you might think of a solution like this, in which **T** is used as the type parameter:

```
// This won't work!
// Determine if two averages are the same.
boolean sameAvg(Stats<T> ob) {
  if(average() == ob.average())
    return true;

  return false;
}
```

The trouble with this attempt is that it will work only with other **Stats** objects whose type is the same as the invoking object. For example, if the invoking object is of type **Stats<Integer>**, then the parameter **ob** must also be of type **Stats<Integer>**. It can't be used to compare the average of an object of type

Stats<Double> with the average of an object of type **Stats<Short>**, for example. Therefore, this approach won't work except in a very narrow context and does not yield a general (that is, generic) solution.

To create a generic **sameAvg( )** method, you must use another feature of Java generics: the *wildcard* argument. The wildcard argument is specified by the **?**, and it represents an unknown type. Using a wildcard, here is one way to write the **sameAvg( )** method:

```
// Determine if two averages are the same.
// Notice the use of the wildcard.
boolean sameAvg(Stats<?> ob) {
  if(average() == ob.average())
    return true;

  return false;
}
```

Here, **Stats<?>** matches any **Stats** object, allowing any two **Stats** objects to have their averages compared. The following program demonstrates this:

```
// Use a wildcard.
class Stats<T extends Number> {
  T[] nums; // array of Number or subclass

  // Pass the constructor a reference to
  // an array of type Number or subclass.
  Stats(T[] o) {
    nums = o;
  }

  // Return type double in all cases.
  double average() {
    double sum = 0.0;

    for(int i=0; i < nums.length; i++)
      sum += nums[i].doubleValue();
```

```
    return sum / nums.length;
  }

  // Determine if two averages are the same.
  // Notice the use of the wildcard.
  boolean sameAvg(Stats<?> ob) {
    if(average() == ob.average())
      return true;

    return false;
  }
}

// Demonstrate wildcard.
class WildcardDemo {
  public static void main(String args[]) {
    Integer inums[] = { 1, 2, 3, 4, 5 };
    Stats<Integer> iob = new Stats<Integer>(inums);
    double v = iob.average();
    System.out.println("iob average is " + v);

    Double dnums[] = { 1.1, 2.2, 3.3, 4.4, 5.5 };
    Stats<Double> dob = new Stats<Double>(dnums);
    double w = dob.average();
    System.out.println("dob average is " + w);

    Float fnums[] = { 1.0F, 2.0F, 3.0F, 4.0F, 5.0F };
    Stats<Float> fob = new Stats<Float>(fnums);
    double x = fob.average();
    System.out.println("fob average is " + x);

    // See which arrays have same average.
    System.out.print("Averages of iob and dob ");
    if(iob.sameAvg(dob))
      System.out.println("are the same.");
    else
      System.out.println("differ.");

    System.out.print("Averages of iob and fob ");
    if(iob.sameAvg(fob))
      System.out.println("are the same.");
    else
      System.out.println("differ.");
  }
}
```

The output is shown here:

```
iob average is 3.0
dob average is 3.3
fob average is 3.0
Averages of iob and dob differ.
Averages of iob and fob are the same.
```

One last point: It is important to understand that the wildcard does not affect what type of **Stats** objects can be created. This is governed by the **extends** clause in the **Stats** declaration. The wildcard simply matches any *valid* **Stats** object.

Bounded Wildcards

Wildcard arguments can be bounded in much the same way that a type parameter can be bounded. A bounded wildcard is especially important when you are creating a generic type that will operate on a class hierarchy. To understand why, let’s work through an example. Consider the following hierarchy of classes that encapsulate coordinates:

```
// Two-dimensional coordinates.
class TwoD {
  int x, y;

  TwoD(int a, int b) {
    x = a;
    y = b;
  }
}

// Three-dimensional coordinates.
class ThreeD extends TwoD {
  int z;

  ThreeD(int a, int b, int c) {
    super(a, b);
    z = c;
  }
}

// Four-dimensional coordinates.
class FourD extends ThreeD {
  int t;

  FourD(int a, int b, int c, int d) {
    super(a, b, c);
    t = d;
  }
}
```

At the top of the hierarchy is **TwoD**, which encapsulates a two-dimensional, XY coordinate. **TwoD** is inherited by **ThreeD**, which adds a third dimension, creating an XYZ coordinate. **ThreeD** is inherited by **FourD**, which adds a fourth dimension (time), yielding a four-dimensional coordinate.

Shown next is a generic class called **Coords**, which stores an array of coordinates:

```
// This class holds an array of coordinate objects.
class Coords<T extends TwoD> {
  T[] coords;

  Coords(T[] o) { coords = o; }
}
```

Notice that **Coords** specifies a type parameter bounded by **TwoD**. This means that any array stored in a **Coords** object will contain objects of type **TwoD** or one of its subclasses.

Now, assume that you want to write a method that displays the X and Y coordinates for each element in the **coords** array of a **Coords** object. Because all types of **Coords** objects have at least two coordinates (X and Y), this is easy to do using a wildcard, as shown here:

```
static void showXY(Coords<?> c) {
  System.out.println("X Y Coordinates:");
  for(int i=0; i < c.coords.length; i++)
    System.out.println(c.coords[i].x + " " +
                       c.coords[i].y);
   System.out.println();
}
```

Because **Coords** is a bounded generic type that specifies **TwoD** as an upper bound, all objects that can be used to create a **Coords** object will be arrays of type **TwoD**, or of classes derived from **TwoD**. Thus, **showXY( )** can display the contents of any **Coords** object.

However, what if you want to create a method that displays the X, Y, and Z coordinates of a **ThreeD** or **FourD** object? The trouble is that not all **Coords** objects will have three coordinates, because a **Coords<TwoD>** object will only have X and Y. Therefore, how do you write a method that displays the X, Y, and Z coordinates for **Coords<ThreeD>** and **Coords<FourD>** objects, while preventing that method from being used with **Coords<TwoD>** objects? The answer is the *bounded wildcard argument*.

A bounded wildcard specifies either an upper bound or a lower bound for the type argument. This enables you to restrict the types of objects upon which a method will operate. The most common bounded wildcard is the upper bound, which is created using an **extends** clause in much the same way it is used to create a bounded type.

Using a bounded wildcard, it is easy to create a method that displays the X, Y, and Z coordinates of a **Coords** object, if that object actually has those three coordinates. For example, the following **showXYZ( )** method shows the X, Y, and Z coordinates of the elements stored in a **Coords** object, if those elements are actually of type **ThreeD** (or are derived from **ThreeD**):

```
static void showXYZ(Coords<? extends ThreeD> c) {
  System.out.println("X Y Z Coordinates:");
  for(int i=0; i < c.coords.length; i++)
    System.out.println(c.coords[i].x + " " +
                       c.coords[i].y + " " +
                       c.coords[i].z);
  System.out.println();
}
```

Notice that an **extends** clause has been added to the wildcard in the declaration of parameter **c**. It states that the **?** can match any type as long as it is **ThreeD**, or a class derived from **ThreeD**. Thus, the **extends** clause establishes an upper bound that the **?** can match. Because of this bound, **showXYZ( )** can be called with references to objects of type **Coords<ThreeD>** or **Coords<FourD>**, but not with a reference of type **Coords<TwoD>**. Attempting to call **showXZY( )** with a **Coords<TwoD>** reference results in a compile-time error, thus ensuring type safety.

Here is an entire program that demonstrates the actions of a bounded wildcard argument:

```
// Bounded Wildcard arguments.

// Two-dimensional coordinates.
class TwoD {
  int x, y;

  TwoD(int a, int b) {
    x = a;
    y = b;
  }
}

// Three-dimensional coordinates.
class ThreeD extends TwoD {
  int z;

  ThreeD(int a, int b, int c) {
    super(a, b);
    z = c;
  }
}

// Four-dimensional coordinates.
class FourD extends ThreeD {
  int t;

  FourD(int a, int b, int c, int d) {
    super(a, b, c);
    t = d;
  }
}

// This class holds an array of coordinate objects.
class Coords<T extends TwoD> {
  T[] coords;

  Coords(T[] o) { coords = o; }
}

// Demonstrate a bounded wildcard.
class BoundedWildcard {
  static void showXY(Coords<?> c) {
    System.out.println("X Y Coordinates:");
    for(int i=0; i < c.coords.length; i++)
      System.out.println(c.coords[i].x + " " +
                         c.coords[i].y);
    System.out.println();
  }

  static void showXYZ(Coords<? extends ThreeD> c) {
    System.out.println("X Y Z Coordinates:");
    for(int i=0; i < c.coords.length; i++)
```

```
      System.out.println(c.coords[i].x + " " +
                         c.coords[i].y + " " +
                         c.coords[i].z);
    System.out.println();
  }

  static void showAll(Coords<? extends FourD> c) {
    System.out.println("X Y Z T Coordinates:");
    for(int i=0; i < c.coords.length; i++)
      System.out.println(c.coords[i].x + " " +
                         c.coords[i].y + " " +
                         c.coords[i].z + " " +
                         c.coords[i].t);
    System.out.println();
  }

  public static void main(String args[]) {
    TwoD td[] = {
      new TwoD(0, 0),
      new TwoD(7, 9),
      new TwoD(18, 4),
      new TwoD(-1, -23)
    };

    Coords<TwoD> tdlocs = new Coords<TwoD>(td);

    System.out.println("Contents of tdlocs.");
    showXY(tdlocs); // OK, is a TwoD
//  showXYZ(tdlocs); // Error, not a ThreeD
//  showAll(tdlocs); // Error, not a FourD

    // Now, create some FourD objects.
    FourD fd[] = {
      new FourD(1, 2, 3, 4),
      new FourD(6, 8, 14, 8),
      new FourD(22, 9, 4, 9),
      new FourD(3, -2, -23, 17)
    };

    Coords<FourD> fdlocs = new Coords<FourD>(fd);

    System.out.println("Contents of fdlocs.");
    // These are all OK.
    showXY(fdlocs);
    showXYZ(fdlocs);
    showAll(fdlocs);
  }
}
```

The output from the program is shown here:

```
Contents of tdlocs.
X Y Coordinates:
0 0
7 9
18 4
-1 -23

Contents of fdlocs.
X Y Coordinates:
1 2
6 8
22 9
3 -2

X Y Z Coordinates:
1 2 3
6 8 14
22 9 4
3 -2 -23

X Y Z T Coordinates:
1 2 3 4
6 8 14 8
22 9 4 9
3 -2 -23 17
```

Notice these commented-out lines:

```
// showXYZ(tdlocs); // Error, not a ThreeD
// showAll(tdlocs); // Error, not a FourD
```

Because **tdlocs** is a **Coords(TwoD)** object, it cannot be used to call **showXYZ( )** or **showAll( )** because bounded wildcard arguments in their declarations prevent it. To prove this to yourself, try removing the comment symbols, and then attempt to compile the program. You will receive compilation errors because of the type mismatches.

In general, to establish an upper bound for a wildcard, use the following type of wildcard expression:

<? extends *superclass*>

where *superclass* is the name of the class that serves as the upper bound.

Remember, this is an inclusive clause because the class forming the upper bound (that is, specified by *superclass*) is also within bounds.

You can also specify a lower bound for a wildcard by adding a **super** clause to a wildcard declaration. Here is its general form:

<? super *subclass*>

In this case, only classes that are superclasses of *subclass* are acceptable arguments. This is an inclusive clause.

Creating a Generic Method

As the preceding examples have shown, methods inside a generic class can make use of a class' type parameter and are, therefore, automatically generic relative to the type parameter. However, it is possible to declare a generic method that uses one or more type parameters of its own. Furthermore, it is possible to create a generic method that is enclosed within a non-generic class.

Let's begin with an example. The following program declares a non-generic class called **GenMethDemo** and a static generic method within that class called **isIn( )**. The **isIn( )** method determines if an object is a member of an array. It can be used with any type of object and array as long as the array contains objects that are compatible with the type of the object being sought.

```
// Demonstrate a simple generic method.
class GenMethDemo {

  // Determine if an object is in an array.
  static <T extends Comparable<T>, V extends T> boolean isIn(T x, V[] y) {
    for(int i=0; i < y.length; i++)
      if(x.equals(y[i])) return true;

    return false;
  }

  public static void main(String args[]) {

    // Use isIn() on Integers.
    Integer nums[] = { 1, 2, 3, 4, 5 };

    if(isIn(2, nums))
      System.out.println("2 is in nums");

    if(!isIn(7, nums))
      System.out.println("7 is not in nums");

    System.out.println();

    // Use isIn() on Strings.
    String strs[] = { "one", "two", "three",
                      "four", "five" };

    if(isIn("two", strs))
      System.out.println("two is in strs");

    if(!isIn("seven", strs))
      System.out.println("seven is not in strs");

    // Oops! Won't compile! Types must be compatible.
//    if(isIn("two", nums))
//      System.out.println("two is in strs");
  }
}
```

The output from the program is shown here:

```
2 is in nums
7 is not in nums
```

```
two is in strs
seven is not in strs
```

Let's examine **isIn( )** closely. First, notice how it is declared by this line:

```
static <T extends Comparable<T>, V extends T> boolean isIn(T x, V[]
y) {
```

The type parameters are declared *before* the return type of the method. Also note that **T** extends **Comparable<T>**. **Comparable** is an interface declared in **java.lang.** A class that implements **Comparable** defines objects that can be ordered. Thus, requiring an upper bound of **Comparable** ensures that **isIn**( ) can be used only with objects that are capable of being compared. **Comparable** is generic, and its type parameter specifies the type of objects that it compares. (Shortly, you will see how to create a generic interface.) Next, notice that the type **V** is upper-bounded by **T**. Thus, **V** must either be the same as type **T**, or a subclass of **T**. This relationship enforces that **isIn( )** can be called only with arguments that are compatible with each other. Also notice that **isIn( )** is static, enabling it to be called independently of any object. Understand, though, that generic methods can be either static or non-static. There is no restriction in this regard.

Now, notice how **isIn( )** is called within **main( )** by use of the normal call syntax, without the need to specify type arguments. This is because the types of the arguments are automatically discerned, and the types of **T** and **V** are adjusted accordingly. For example, in the first call:

```
if(isIn(2, nums))
```

the type of the first argument is **Integer** (due to autoboxing), which causes **Integer** to be substituted for **T**. The base type of the second argument is also **Integer**, which makes **Integer** a substitute for **V**, too. In the second call, **String** types are used, and the types of **T** and **V** are replaced by **String**.

Although type inference will be sufficient for most generic method calls, you can explicitly specify the type argument if needed. For example, here is how the first call to **isIn( )** looks when the type arguments are specified:

```
GenMethDemo.<Integer, Integer>isIn(2, nums)
```

Of course, in this case, there is nothing gained by specifying the type arguments. Furthermore, JDK 8 improved type inference as it relates to methods. As a result, there are fewer cases in which explicit type arguments are needed.

Now, notice the commented-out code, shown here:

```
//     if(isIn("two", nums))
//       System.out.println("two is in strs");
```

If you remove the comments and then try to compile the program, you will receive an error. The reason is that the type parameter **V** is bounded by **T** in the **extends** clause in **V**'s declaration. This means that **V** must be either type **T**, or a subclass of **T**. In this case, the first argument is of type **String**, making **T** into **String**, but the second argument is of type **Integer**, which is not a subclass of **String**. This causes a compile-time type-mismatch error. This ability to enforce type safety is one of the most important advantages of generic methods.

The syntax used to create **isIn( )** can be generalized. Here is the syntax for a generic method:

<*type-param-list* > *ret-type meth-name* (*param-list*) { // …

In all cases, *type-param-list* is a comma-separated list of type parameters. Notice that for a generic method, the type parameter list precedes the return type.

Generic Constructors

It is possible for constructors to be generic, even if their class is not. For example, consider the following short program:

```
// Use a generic constructor.
class GenCons {
  private double val;

  <T extends Number> GenCons(T arg) {
    val = arg.doubleValue();
  }

  void showval() {
    System.out.println("val: " + val);
  }
}

class GenConsDemo {
  public static void main(String args[]) {

    GenCons test = new GenCons(100);
    GenCons test2 = new GenCons(123.5F);

    test.showval();
    test2.showval();
  }
}
```

The output is shown here:

```
val: 100.0
val: 123.5
```

Because **GenCons( )** specifies a parameter of a generic type, which must be a subclass of **Number**, **GenCons( )** can be called with any numeric type, including **Integer**, **Float**, or **Double**. Therefore, even though **GenCons** is not a generic class, its constructor is generic.

Generic Interfaces

In addition to generic classes and methods, you can also have generic interfaces. Generic interfaces are specified just like generic classes. Here is an example. It creates an interface called **MinMax** that declares the methods **min( )** and **max( )**,

which are expected to return the minimum and maximum value of some set of objects.

```
// A generic interface example.

// A Min/Max interface.
interface MinMax<T extends Comparable<T>> {
  T min();
  T max();
}

// Now, implement MinMax
class MyClass<T extends Comparable<T>> implements MinMax<T> {
  T[] vals;

  MyClass(T[] o) { vals = o; }

  // Return the minimum value in vals.
  public T min() {
    T v = vals[0];

    for(int i=1; i < vals.length; i++)
      if(vals[i].compareTo(v) < 0) v = vals[i];

    return v;
  }

  // Return the maximum value in vals.
  public T max() {
    T v = vals[0];

    for(int i=1; i < vals.length; i++)
      if(vals[i].compareTo(v) > 0) v = vals[i];

    return v;
  }
}

class GenIFDemo {
  public static void main(String args[]) {
    Integer inums[] = {3, 6, 2, 8, 6 };
    Character chs[] = {'b', 'r', 'p', 'w' };

    MyClass<Integer> iob = new MyClass<Integer>(inums);
    MyClass<Character> cob = new MyClass<Character>(chs);

    System.out.println("Max value in inums: " + iob.max());
    System.out.println("Min value in inums: " + iob.min());
```

```
    System.out.println("Max value in chs: " + cob.max());
    System.out.println("Min value in chs: " + cob.min());
  }
}
```

The output is shown here:

```
Max value in inums: 8
Min value in inums: 2
Max value in chs: w
Min value in chs: b
```

Although most aspects of this program should be easy to understand, a couple of key points need to be made. First, notice that **MinMax** is declared like this:

```
interface MinMax<T extends Comparable<T>> {
```

In general, a generic interface is declared in the same way as is a generic class. In this case, the type parameter is **T**, and its upper bound is **Comparable**. As explained earlier, **Comparable** is an interface defined by **java.lang** that specifies how objects are compared. Its type parameter specifies the type of the objects being compared.

Next, **MinMax** is implemented by **MyClass**. Notice the declaration of **MyClass**, shown here:

```
class MyClass<T extends Comparable<T>> implements MinMax<T> {
```

Pay special attention to the way that the type parameter **T** is declared by **MyClass** and then passed to **MinMax**. Because **MinMax** requires a type that implements **Comparable**, the implementing class (**MyClass** in this case) must specify the same bound. Furthermore, once this bound has been established, there is no need to specify it again in the **implements** clause. In fact, it would be wrong to do so. For example, this line is incorrect and won't compile:

```
// This is wrong!
class MyClass<T extends Comparable<T>>
        implements MinMax<T extends Comparable<T>> {
```

Once the type parameter has been established, it is simply passed to the interface without further modification.

In general, if a class implements a generic interface, then that class must also

be generic, at least to the extent that it takes a type parameter that is passed to the interface. For example, the following attempt to declare **MyClass** is in error:

```
class MyClass implements MinMax<T> { // Wrong!
```

Because **MyClass** does not declare a type parameter, there is no way to pass one to **MinMax**. In this case, the identifier **T** is simply unknown, and the compiler reports an error. Of course, if a class implements a *specific type* of generic interface, such as shown here:

```
class MyClass implements MinMax<Integer> { // OK
```

then the implementing class does not need to be generic.

The generic interface offers two benefits. First, it can be implemented for different types of data. Second, it allows you to put constraints (that is, bounds) on the types of data for which the interface can be implemented. In the **MinMax** example, only types that implement the **Comparable** interface can be passed to **T**.

Here is the generalized syntax for a generic interface:

interface *interface-name*<*type-param-list*> { // …

Here, *type-param-list* is a comma-separated list of type parameters. When a generic interface is implemented, you must specify the type arguments, as shown here:

class *class-name*<*type-param-list*>
    implements *interface-name*<*type-arg-list*> {

Raw Types and Legacy Code

Because support for generics did not exist prior to JDK 5, it was necessary to provide some transition path from old, pre-generics code. Furthermore, this transition path had to enable pre-generics code to remain functional while at the same time being compatible with generics. In other words, pre-generics code had to be able to work with generics, and generic code had to be able to work with pre-generics code.

To handle the transition to generics, Java allows a generic class to be used without any type arguments. This creates a *raw type* for the class. This raw type

is compatible with legacy code, which has no knowledge of generics. The main drawback to using the raw type is that the type safety of generics is lost.

Here is an example that shows a raw type in action:

```
// Demonstrate a raw type.
class Gen<T> {

  T ob; // declare an object of type T

  // Pass the constructor a reference to
  // an object of type T.
  Gen(T o) {
    ob = o;
  }

  // Return ob.
  T getob() {
    return ob;
  }
}

// Demonstrate raw type.
class RawDemo {
  public static void main(String args[]) {

    // Create a Gen object for Integers.
    Gen<Integer> iOb = new Gen<Integer>(88);
```

```
    // Create a Gen object for Strings.
    Gen<String> strOb = new Gen<String>("Generics Test");

    // Create a raw-type Gen object and give it
    // a Double value.
    Gen raw = new Gen(Double.valueOf(98.6));

    // Cast here is necessary because type is unknown.
    double d = (Double) raw.getob();
    System.out.println("value: " + d);

    // The use of a raw type can lead to run-time
    // exceptions. Here are some examples.

    // The following cast causes a run-time error!
//    int i = (Integer) raw.getob(); // run-time error

    // This assignment overrides type safety.
    strOb = raw; // OK, but potentially wrong
//    String str = strOb.getob(); // run-time error

    // This assignment also overrides type safety.
    raw = iOb; // OK, but potentially wrong
//    d = (Double) raw.getob(); // run-time error
  }
}
```

This program contains several interesting things. First, a raw type of the generic **Gen** class is created by the following declaration:

```
Gen raw = new Gen(Double.valueOf(98.6));
```

Notice that no type arguments are specified. In essence, this creates a **Gen** object whose type **T** is replaced by **Object**.

A raw type is not type safe. Thus, a variable of a raw type can be assigned a reference to any type of **Gen** object. The reverse is also allowed; a variable of a specific **Gen** type can be assigned a reference to a raw **Gen** object. However, both operations are potentially unsafe because the type checking mechanism of generics is circumvented.

This lack of type safety is illustrated by the commented-out lines at the end of the program. Let's examine each case. First, consider the following situation:

```
// int i = (Integer) raw.getob(); // run-time error
```

In this statement, the value of **ob** inside **raw** is obtained, and this value is cast to **Integer**. The trouble is that **raw** contains a **Double** value, not an integer value. However, this cannot be detected at compile time because the type of **raw** is unknown. Thus, this statement fails at run time.

The next sequence assigns to a **strOb** (a reference of type **Gen<String>**) a reference to a raw **Gen** object:

```
    strOb = raw; // OK, but potentially wrong
//    String str = strOb.getob(); // run-time error
```

The assignment, itself, is syntactically correct, but questionable. Because **strOb** is of type **Gen<String>**, it is assumed to contain a **String**. However, after the assignment, the object referred to by **strOb** contains a **Double**. Thus, at run time, when an attempt is made to assign the contents of **strOb** to **str**, a run-time error results because **strOb** now contains a **Double**. Thus, the assignment of a raw reference to a generic reference bypasses the type-safety mechanism.

The following sequence inverts the preceding case:

```
    raw = iOb; // OK, but potentially wrong
//    d = (Double) raw.getob(); // run-time error
```

Here, a generic reference is assigned to a raw reference variable. Although this is syntactically correct, it can lead to problems, as illustrated by the second line. In this case, **raw** now refers to an object that contains an **Integer** object, but the cast assumes that it contains a **Double**. This error cannot be prevented at compile time. Rather, it causes a run-time error.

Because of the potential for danger inherent in raw types, **javac** displays *unchecked warnings* when a raw type is used in a way that might jeopardize type safety. In the preceding program, these lines generate unchecked warnings:

```
Gen raw = new Gen(Double.valueOf(98.6));

strOb = raw; // OK, but potentially wrong
```

In the first line, it is the call to the **Gen** constructor without a type argument that causes the warning. In the second line, it is the assignment of a raw reference to

a generic variable that generates the warning.

At first, you might think that this line should also generate an unchecked warning, but it does not:

```
raw = iOb; // OK, but potentially wrong
```

No compiler warning is issued because the assignment does not cause any *further* loss of type safety than had already occurred when **raw** was created.

One final point: You should limit the use of raw types to those cases in which you must mix legacy code with newer, generic code. Raw types are simply a transitional feature and not something that should be used for new code.

Generic Class Hierarchies

Generic classes can be part of a class hierarchy in just the same way as a non-generic class. Thus, a generic class can act as a superclass or be a subclass. The key difference between generic and non-generic hierarchies is that in a generic hierarchy, any type arguments needed by a generic superclass must be passed up the hierarchy by all subclasses. This is similar to the way that constructor arguments must be passed up a hierarchy.

Using a Generic Superclass

Here is a simple example of a hierarchy that uses a generic superclass:

```
// A simple generic class hierarchy.
class Gen<T> {
  T ob;

  Gen(T o) {
    ob = o;
  }

  // Return ob.
  T getob() {
    return ob;
  }
}

// A subclass of Gen.
class Gen2<T> extends Gen<T> {
  Gen2(T o) {
    super(o);
  }
}
```

In this hierarchy, **Gen2** extends the generic class **Gen**. Notice how **Gen2** is declared by the following line:

```
class Gen2<T> extends Gen<T> {
```

The type parameter **T** is specified by **Gen2** and is also passed to **Gen** in the **extends** clause. This means that whatever type is passed to **Gen2** will also be passed to **Gen**. For example, this declaration,

```
Gen2<Integer> num = new Gen2<Integer>(100);
```

passes **Integer** as the type parameter to **Gen**. Thus, the **ob** inside the **Gen** portion of **Gen2** will be of type **Integer**.

Notice also that **Gen2** does not use the type parameter **T** except to support the **Gen** superclass. Thus, even if a subclass of a generic superclass would otherwise not need to be generic, it still must specify the type parameter(s) required by its generic superclass.

Of course, a subclass is free to add its own type parameters, if needed. For example, here is a variation on the preceding hierarchy in which **Gen2** adds a

type parameter of its own:

```
// A subclass can add its own type parameters.
class Gen<T> {
  T ob; // declare an object of type T

  // Pass the constructor a reference to
  // an object of type T.
```

```
  Gen(T o) {
    ob = o;
  }

  // Return ob.
  T getob() {
    return ob;
  }
}

// A subclass of Gen that defines a second
// type parameter, called V.
class Gen2<T, V> extends Gen<T> {
  V ob2;

  Gen2(T o, V o2) {
    super(o);
    ob2 = o2;
  }

  V getob2() {
    return ob2;
  }
}

// Create an object of type Gen2.
class HierDemo {
  public static void main(String args[]) {

    // Create a Gen2 object for String and Integer.
    Gen2<String, Integer> x =
      new Gen2<String, Integer>("Value is: ", 99);

    System.out.print(x.getob());
    System.out.println(x.getob2());
  }
}
```

Notice the declaration of this version of **Gen2**, which is shown here:

```
class Gen2<T, V> extends Gen<T> {
```

Here, **T** is the type passed to **Gen**, and **V** is the type that is specific to **Gen2**. **V** is used to declare an object called **ob2**, and as a return type for the method **getob2( )**. In **main( )**, a **Gen2** object is created in which type parameter **T** is **String**, and type parameter **V** is **Integer**. The program displays the following, expected, result:

```
Value is: 99
```

A Generic Subclass

It is perfectly acceptable for a non-generic class to be the superclass of a generic subclass. For example, consider this program:

```
// A non-generic class can be the superclass
// of a generic subclass.

// A non-generic class.
class NonGen {
  int num;

  NonGen(int i) {
    num = i;
  }

  int getnum() {
    return num;
  }
}

// A generic subclass.
class Gen<T> extends NonGen {
  T ob; // declare an object of type T

  // Pass the constructor a reference to
  // an object of type T.
  Gen(T o, int i) {
    super(i);
    ob = o;
  }

  // Return ob.
  T getob() {
    return ob;
  }
}

// Create a Gen object.
class HierDemo2 {
  public static void main(String args[]) {

    // Create a Gen object for String.
    Gen<String> w = new Gen<String>("Hello", 47);

    System.out.print(w.getob() + " ");
    System.out.println(w.getnum());
  }
}
```