Chapter 13. Inheritance and Polymorphism

Objects are often categorized into groups that share similar characteristics. To illustrate:

- People who work as *internists*, *pediatricians*, *surgeons*, *gynecologists*, *neurologists*, *general practitioners*, and other specialists have something in common: they are all *doctors*.
- Vehicles such as *bicycles*, *cars*, *motorcycles*, *trains*, *ships*, *boats* and *airplanes* are all mobile machines.
- The elements *helium*, *neon*, *argon*, *krypton*, *xenon*, and *radon* are known as the *inert* (or *noble*) *gasses* because each has the full complement of eight electrons in its outermost atomic shell, and thus does not react readily with other elements.

These are just a few of the many situations in which we organize objects into groups because of their common characteristics. When two or more objects have some characteristic in common, those objects are said to be *related* by virtue of sharing that characteristic.

Much of the history of science has involved the classification of objects by identifying their common characteristics. For example, when biologists discover a new species, they study all of its characteristics to determine where it fits into their elaborate classification scheme.

One of the aims of object-oriented programming is to simplify the process of building software models of real-world objects. Since real-world objects may be related to one another, an object-oriented language must provide some mechanism for modeling such relationships. In Java, the keyword `extends` serves this purpose. In this chapter, we study Java's `extends` mechanism, and see how it can be used to save coding effort in a carefully designed system.

13.1. Example: A Figure-Drawing Application

Consider the problem of building a drawing application that allows a user to draw different sorts of figures on a drawing canvas. This application might look something like the example shown in Figure 13-1. The application should allow users to choose the figures they'd like to draw and the colors they'd like to use from a drawing palette of some sort and to use the mouse to specify where the figures go and how large they are.

This figure-drawing domain is similar to the domains discussed in the introduction in that it contains a variety of objects such as squares, rectangles, ellipses, lines and squiggles, all of which share the properties common to geometric figures. Such figures have screen locations specifying where they are to be drawn on

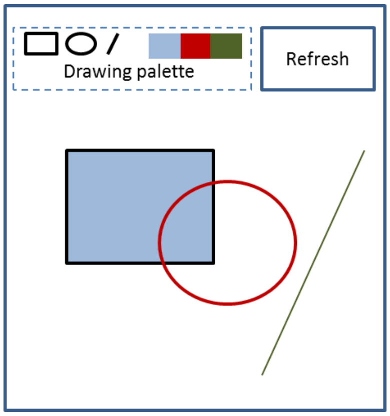


Figure 13-1. A simple drawing application

the canvas, fill settings specifying whether they are to be filled with color or merely outlined, and color settings specifying the colors to use. There are also interesting relationships between the different figure types. Squares are also rectangles but not the reverse. Ellipses can be filled, but not lines.

A programmer could build different classes to model each figure type, e.g., `Rectangle`, `Ellipse`, `Line`, etc., but that would likely lead to considerable amounts of redundant code. For example, every figure class would have to store an instance variable specifying their color and provide largely identical constructors, accessors and mutators for initializing and managing that variable's value. Redundancy such as this is rarely a good programming practice.

This chapter introduces the techniques offered by object-oriented programming for implementing applications such as this in a more concise and consistent manner.

13.2. Modeling Objects and Relationships

The object-oriented programming (OOP) paradigm is based on three fundamental mechanisms:

- Encapsulation
- Inheritance
- Polymorphism

Encapsulation, the focus of Chapter 9, is the language construct that bundles data and methods into a single class specification. Inheritance and polymorphism are addressed in the following sections. As we'll see, inheritance is a mechanism for sharing common features amongst classes while polymorphism is a mechanism for designating unique features for each class.

13.2.1. Revisiting the Example

Before discussing inheritance and polymorphism, this section presents a first iteration of the figure-drawing application introduced in Section 13.1, which we will call Simpledraw. It is not difficult to implement a rectangle-drawing version of Simpledraw using mechanisms covered earlier in the text.

Rectangle.java

```
/**
 * A simple rectangle-drawing class
 *
 * @author kvlinden
 * @version Fall, 2009
 */
public class Rectangle {

      private Point myStart;
      private int myColor;
      private int myWidth, myHeight;
      private boolean myFilled;

      public Rectangle(Point start, int width, int height,
                       int color, boolean filled) {
            myStart = start;
            myColor = color;
            myWidth = width;
            myHeight = height;
            myFilled = filled;
      }

      public int getColor() {
            return myColor;
      }
      public void setColor(int color) {
            myColor = color;
      }

      public void render(PApplet p) {
            p.stroke(myColor);
            if (myFilled) {
                  p.fill(myColor);
            } else {
                  p.noFill();
            }
            p.rect(myStart.x, myStart.y, myWidth, myHeight);
      }
}
```

The class models a rectangle by encapsulating:

- instance variables representing the rectangle's starting point (its upper left point), its color, width, height and a boolean indicating whether it is to be filled with color or simply outlined
- methods specifying how to construct and draw the figure, and an accessor and mutator for the color attribute.

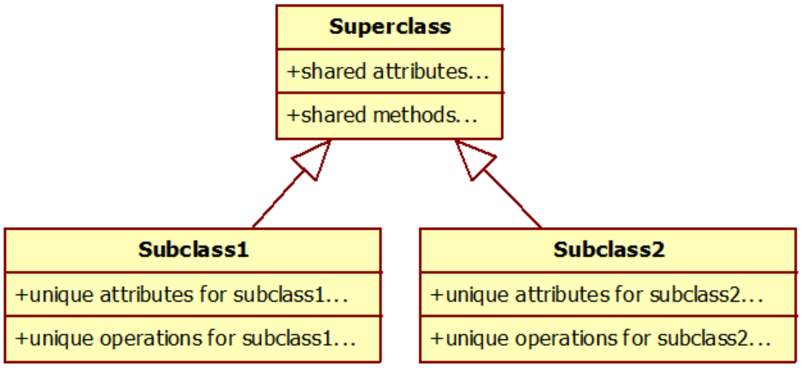
As has been our practice since Chapter 11, the `render()` method receives the drawing context from its calling object, which must be a `PApplet`, and uses Processing-based drawing methods to render the rectangle on the canvas.

As it stands, this class is a perfectly appropriate model of a rectangle, but when we consider adding support for ellipses, lines and other figure types, it's clear that they too will need to represent a color attribute and provide support for that attribute in the constructor, draw methods, accessors and mutators. As mentioned in the previous section, we'd like to avoid reproducing this amount of redundant code; redundant code is time-consuming to produce and can lead to inconsistencies, say, in the way color is handled for each of the figure types. We would prefer to specify the color attribute in one place and allow all the figure objects to share that attribute.

13.3. Inheritance

Inheritance is a language construct that supports the sharing of features amongst different objects. Consider the domain of vehicles, which includes bicycles, skateboards, cars and jets. On the one hand, vehicles of these types share some common features; they tend to be manufactured by particular companies and identified by a model name or number. For example, the "7.4FX" is a particular bicycle model manufactured by Trek Corporation and the "Rocket" is a particular skateboard model manufactured by Ally Corporation. On the other hand, each of these vehicle types tends to have distinguishing features not shared by other vehicle types. For example, bicycles can be assessed by their number of gears, e.g., 27 for the Trek 7.4FX, while skateboards can be assessed by the length of their board, e.g., the Rocket has a 31.5-inch board.

Inheritance allows a programmer to separate those attributes and behaviors that are shared between vehicle types and those that are unique to each particular type. The shared features are collected in a single class known as the parent or *superclass* and the unique features are separated into the child or *subclasses*. This can be visualized as follows.


Superclass
+shared attributes...
+shared methods...
Subclass1
+unique attributes for subclass1...
+unique operations for subclass1...
Subclass2
+unique attributes for subclass2...
+unique operations for subclass2...

In class diagrams such as this, subclasses point up to their superclass. The attributes and behaviors implemented in the superclass are "inherited" by all the subclasses. The attributes and behaviors implemented in one of the subclasses are unique that subclass. In a sense, the features shared by subclass1 and subclass 2, that might otherwise have been implemented separately in each of the subclasses, can be collected and "raised up" into the single shared superclass.

Because Java does not implement multiple inheritance, subclasses can only have one superclass. Superclasses, on the other hand, can have many subclasses.

For example, in the vehicles domain, a programmer might implement the brand and model in a vehicle superclass, the engine size in a car subclass and the number of jet engines in a jet subclass.

13.3.1. The `extends` Clause

Inheritance is implemented in Java using the `extends` clause. A class `Subclass1` can inherit attributes and behaviors from another class `Superclass` as follows:

```
class Superclass {
      // attributes and behaviors shared by all subclasses...
}

class Subclass1 extends Superclass {
      // attributes and behaviors unique to Subclass1...
}
```

The `extends Superclass` clause specifies the inheritance. It indicates that any object of type `Subclass1` is also an object of type `Superclass` and thus that a `Subclass1` object can do anything that a `Superclass` object can do. This construct provides considerable power for code sharing and reuse.

For example, in the vehicle domain we could implement a `Vehicle` superclass as follows.

Vehicle.java

```
class Vehicle {

      private String myBrand, myModel;

      public Vehicle() {
            myBrand = "unknown";
            myModel = "unknown";
      }

      public Vehicle(String brand, String model) {
            setBrand(brand);
            setModel(model);
      }

      public String getBrand() {
            return myBrand;
      }

      public void setBrand(String brand) {
            myBrand = brand;
      }

      public String getModel() {
            return myModel;
      }

      public void setModel(String model) {
            myModel = model;
      }

      public String toString() {
            return getBrand() + " " + getModel();
      }
}
```

This class models a vehicle object by storing the brand and model attributes for that object and providing constructors, accessors and mutators for maintaining those attributes. This class is implemented in the same manner that we implemented classes in Chapter 9. Given this (super)class, we can now implement a `Bicycle` subclass as follows.

Bicycle.java

```
class Bicycle extends Vehicle {

        private int myGearCount;

        public Bicycle() {
                myGearCount = 1;
        }

        public Bicycle(int gearCount) {
                setGearCount(gearCount);
        }

        public int getGearCount() {
                return myGearCount;
        }

        public void setGearCount(int gearCount) {
                myGearCount = gearCount;
        }

}
```

This `Bicycle` class inherits all the features of the `Vehicle` class and adds additional features handling the number of gears of the bicycle. Given these class definitions, we can write the following code segment.

Code:

```
Bicycle trek74 = new Bicycle();

trek74.setGearCount(27);
System.out.println(trek74.getGears());

trek74.setBrand("Trek");
trek74.setModel("7.4FX");
System.out.println(trek74);
```

Output:

```
27
Trek 7.4FX
```

This code segment declares a bicycle object, `trek74`, sets its number of gears to 27 and prints that number out (thus the first line of the output). This is standard behavior for the classes we've worked with in previous chapters, implemented using the `myGearCount` instance variable and its associated accessor and mutator methods. The next segment of code, however, sets the brand and model of the `trek74` object to "Trek" and "7.4FX" respectively and prints the object itself out using the `toString()` method. This behavior is not implemented in the `Bicycle` class itself; it is inherited from the `Vehicle` class. Thus, we can say that a Bicycle object is a Vehicle object in that it can do anything that a Vehicle object can do.

With the features shared by vehicle objects implemented in the Vehicle class, we can now define new vehicle subclasses that share those same features. The following class defines a skateboard class that reuses the vehicle features.

Skateboard.java

```
class Skateboard extends Vehicle {

        private double myBoardLength;

        public Skateboard() {
                myBoardLength = 0;
        }

        public Skateboard(double boardLength) {
                setBoardLength(boardLength);
        }

        public double getBoardLength() {
                return myBoardLength;
        }

        public void setBoardLength(double boardLength) {
                myBoardLength= boardLength;
        }

}
```

This Skateboard class inherits the vehicle features just as the Bicycle class does, as can be seen in the following code segment.

Code:

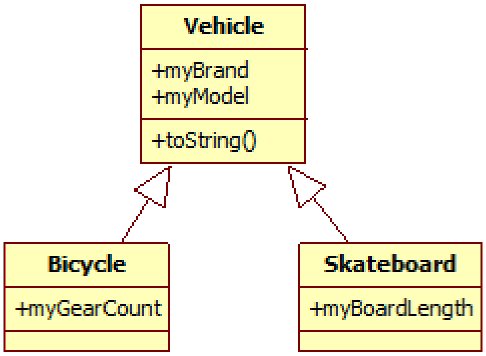
```
        Skateboard board = new Skateboard();

        board.setBoardLength(31.5);
        System.out.println(board.getBoardLength());

        board.setBrand("Ally");
        board.setModel("Rocket");
        System.out.println(board);
```

Output:

```
        31.5
        Ally Rocket
```

As with the Bicycle class, the Skateboard class inherits the support for the brand, model and the toString() method, to which it adds unique support for board length.

This class structure for our vehicle domain can be viewed as follows.

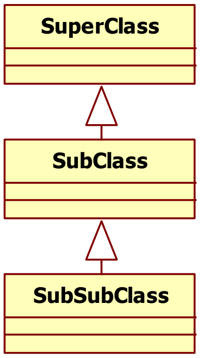


The `Vehicle` class's instance variables, `myBrand` and `myModel`, and its `toString()` method are listed in the Vehicle class box; the associated accessors and mutators are not explicitly listed to save space. Similarly, the `Bicycle` and `Skateboard` each define their own instance variables: `myGearCount` and `myBoardLength` respectively.

13.3.2. Multi-Level Inheritance

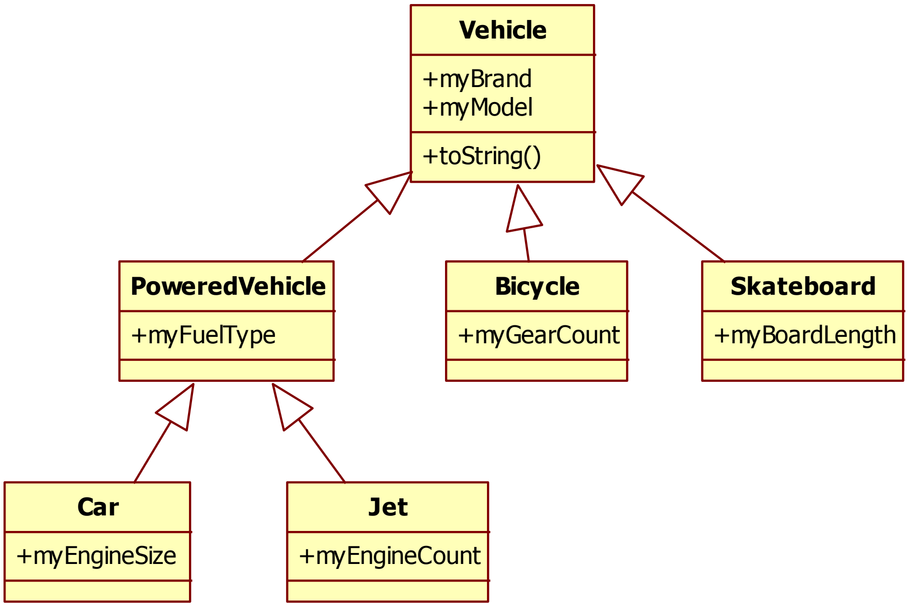
Inheritance is a recursive mechanism and can therefore be used to implement multiple levels of sharing. The Java `extends` clause can be used as shown in the code here on the left to produce the class structure shown on the right.

```
class SuperClass {
        // features shared by all descendants...
}

class SubClass extends SuperClass {
        // features shared by descendants of SubClass...
}

class SubSubClass extends SubClass {
        // features unique to SubSubClass...
}
```



In this structure, objects of type SubSubClass inherit features from both SubClass and SuperClass. This mechanism provides the ability to create tree-shaped class hierarchies that can be used to share features amongst subsets of subclasses.

In the vehicle domain, this can be useful when we introduce cars and jet airplanes. Cars and jets are vehicles that are mechanically powered, and thus share features related to fuel and fuel consumption. Because bicycles and skateboard are not powered, it makes no sense to introduce these features at the level of the `Vehicle` class, but we can introduce a new level in the class hierarchy for powered vehicles as shown here.



In this class structure, all vehicles share the brand and model features, but only the car and jet share the fuel type feature.

PoweredVehicle.java

```
class PoweredVehicle extends Vehicle {

      private String myFuelType;

      public PoweredVehicle() {
            setFuelType("unknown");
      }

      public String getFuelType() {
            return myFuelType;
      }

      public void setFuelType(String fuel) {
            myFuelType = fuel;
      }

}
```

Car.java

```
class Car extends PoweredVehicle {

   private String myEngineSize;

   public Car() {
      myEngineSize = "unknown";
   }

   // accessors/mutators for engine
   // size...
}
```

Jet.java

```
class Jet extends PoweredVehicle {

   private int myEngineCount;

   public Jet() {
      myEngineCount = 0;
   }

   // accessors/mutators for engine
   // count...
}
```

Given these classes we can write the following code segments.

Code:

```
   Car vw = new Car();

   vw.setEngineSize("1.8 liter");
   System.out.println(vw.getEngineSize());

   vw.setFuelType("gasoline");
   System.out.println(vw.getFuelType());

   vw.setBrand("Volkswagon");
   vw.setModel("Golf");
   System.out.println(vw);
```

Output:

```
   1.8 liter
   gasoline
   Volkswagon Golf
```

Code:

```
   Jet lear45 = new Jet();

   lear45.setEngineCount(2);
   System.out.println(lear45.getEngineCount());

   lear45.setFuelType("jet fuel");
   System.out.println(lear45.getFuelType());

   lear45.setBrand("Learjet");
   lear45.setModel("LJ45");
   System.out.println(lear45);
```

Output:

```
   2
   jet fuel
   Learjet LJ45
```

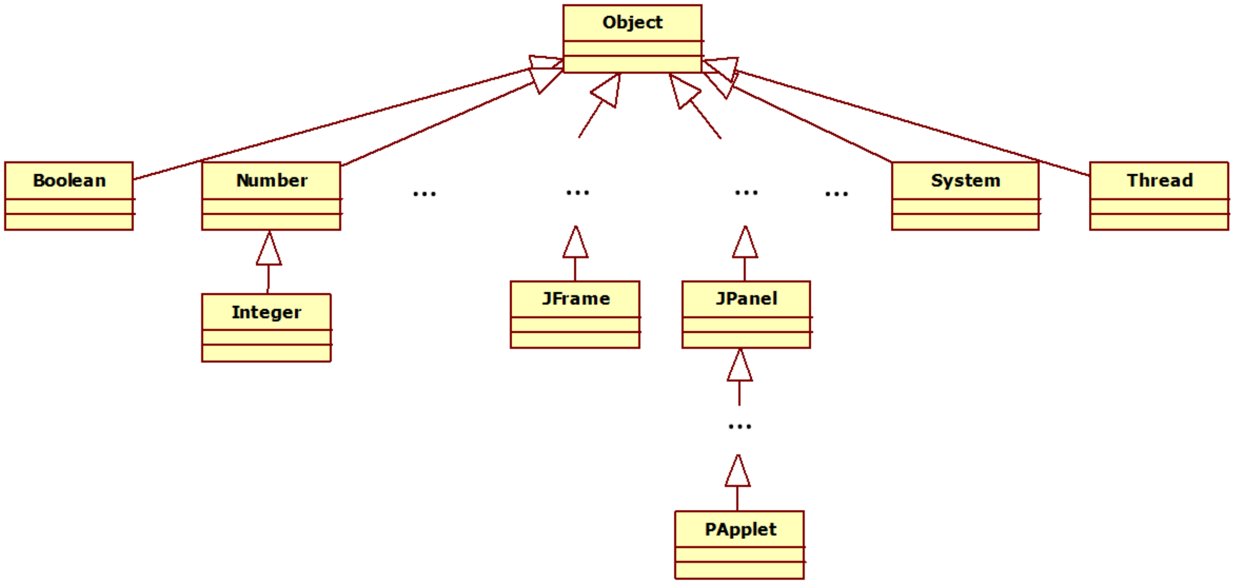
Note how both the `Car` object, `vw`, and the `Jet` object, `lear45`, manage their own unique features: engine size and engine count respectively, but share the fuel type feature from `PoweredVehicle` and the brand and model features from `Vehicle`.

When a method is called on an object, Java looks for a definition of the method in the object's class first, and continues up the class hierarchy until it finds a definition. It uses the first definition it finds. For example, when the `setModel()` method is called on the `vw` object (i.e., `vw.setModel("Golf")`), Java looks first in the `Car` class, then proceeds to the `PoweredVehicle` class and finally to the `Vehicle` class, where it finds a definition.

13.3.3. The Java Class Hierarchy

We have actually been taking advantage of inheritance all along because Java structures its entire API hierarchically[1]. There are far too many classes – more than 4000 in Java 7 – to show, but the root of this hierarchy is the `Object` class, making it the common ancestor for all Java classes, as shown here.

[1] See http://docs.oracle.com/javase/7/docs/api/index.html.



Note that `PApplet` as well as all the other Processing-specific classes are integrated into the Java class hierarchy.[2] In addition, every new class that any programmer writes is made an extension of the `Object` class by default, regardless of whether the programmer explicitly includes the `extends Object` clause or not.

Because of this every class inherits the features of the `Object` class, which include the `toString()`, `clone()` and `equals()` methods. This explains why we can always print an object on the console; every class inherits the `toString()` method from the `Object` class automatically.

13.3.4. Accessing Superclass Constructors

The Java class-construction mechanism provides two useful keywords: `this` and `super`. Both are discussed in this section with respect to their use in accessing constructor methods.

The `this` Keyword

The keyword `this` refers to the current object itself. It is occasionally used to access one constructor from another and also to access data attributes that are out of scope, as shown here.

```
class A {

   private int someValue;

   public A() {
      this(1);                    // Call the explicit-value constructor.
   }
```

[2] See http://processing.googlecode.com/svn/trunk/processing/build/javadoc/core/index.html?processing/core/package-tree.html.

```
   public A(int someValue) {
      this.someValue = someValue;// Access the class instance variable.
   }
}
```

In this code, the default constructor uses `this` to access the explicit-value constructor, passing a default value for the instance variable. The explicit-value constructor must use `this` to access the class instance variable because the parameter of the same name overrides the global definition in the scope of the explicit-value constructor.

The `super` Keyword

The keyword `super` refers to the superclass of the current object. It performs a similar function, but it refers to the immediate superclass of the current class. This is useful when a class needs to access: (1) its superclass's constructor, discussed in this section; and (2) its superclass's methods, discussed in the next section.

While subclasses inherit the attributes and methods of their superclass, they do not inherit their superclass's constructors. To invoke a superclass's constructor, a subclass must use the `super` keyword as shown here.

```
super(argumentList);
```

The argument list provides the arguments required by the superclass's constructor and may be empty for the default constructor. Note that this call to the superclass's constructor must be the first statement in a subclass's constructor.

For the vehicle domain, a programmer will likely want to improve the current implementation of the `Bicycle` class by providing an explicit-value constructor that specifies all the instance variables. This constructor would be invoked as follows.

```
Bicycle feltAR5 = new Bicycle("Felt", "AR5", 30);
```

The current version of the `Bicycle` class does not provide a constructor with this signature because it cannot access the `myBrand` and `myModel` variables it inherits from the `Vehicle` class. They are declared as `private` data items and cannot, therefore, be accessed by any class other than `Vehicle`, even `Vehicle`'s own subclasses.[3]

Instead, a programmer can use the `super` keyword to access the features of the superclass's constructor method. Given the definition of the `Vehicle` class shown in Section 13.3.1, which includes an explicit-value constructor that receives two strings representing the brand and model respectively, we can revise the `Bicycle` class as shown here.

[3] We could declare those instance variables as `public`, but that would lay them open to access from any class, which violates the principle of information hiding. As an alternative, Java provides a `protected` designation, which indicates that the instance variables be accessible to this class and all its descendants. This text does not adopt the practice of using protected data items, but rather implements subclasses to access and manipulate inherited data items through the inherited accessor and mutator methods.

Bicycle.java (revised)

```
1   class Bicycle extends Vehicle {
2   
3           private int myGearCount;
4   
5           public Bicycle() {
6                   myGearCount = 1;
7           }
8   
9           public Bicycle(int gearCount) {
10                  setGearCount(gearCount);
11          }
12  
13          public Bicycle(String brand, String model, int gearCount) {
14                  super(brand, model);
15                  setGearCount(gearCount);
16          }
17  
18          // The accessors and mutators are repeated here...
19  }
```

The new constructor method defined in lines 13-16 can be invoked as shown above. The first two arguments representing the brand and model are passed directly to the `Vehicle` class's explicit-value constructor using the `super` keyword. The gear count argument is then handled directly in the normal way.

By default, Java includes an invocation of the superclass's default constructor for all classes. Thus, the Bicycle class's default constructor is actually implemented as follows.

```
public Bicycle() {
        super();
        myGearCount = 1;
}
```

For this reason, it is generally a good idea to provide a default constructor for every superclass, because this constructor will be called, either explicitly or implicitly, by all the subclasses. Java produces a compiler error if a default constructor is called but is not explicitly defined. For example, if we were to remove the `Vehicle` class's default constructor, Java would signal compiler errors for the default constructors for all its subclasses, i.e., `Bicycle`, `Skateboard` and `PoweredVehicle`.

Because this automatic invocation of the superclass's constructor is performed recursively, constructing an object of some subclass automatically invokes the constructors of all its ancestors, starting with the highest-level constructor and moving down the class hierarchy. For example, constructing a `Car` object, automatically invokes the constructors for the `Object`, `Vehicle`, `PoweredVehicle` and `Car` classes in that order.

13.3.5. Overriding Superclass Methods

Subclasses are not required to use the same definitions of all the methods they inherit; they can replace them with specialized definitions. This is called *overriding* the inherited method. A programmer can override an inherited method as follows.

```
class Superclass {

      // other features of the superclass...

      public int superClassMethod() {
            // do something...
            return 1;
      }
}

class Subclass extends Superclass {

      // other features of the subclass...

      public int superClassMethod() {
            // do something different...
            return 2;
      }
}
```

In this code, the subclass provides its own definition of the superclass's `superClassMethod()`. An object of type `Subclass` will execute its own version of `superClassMethod()`, that is it will "do something different" and return 2 rather than 1.

Note the difference between "overriding" a method as described here and "overloading" a method as described in a previous chapter. In contrast to overriding, overloading a method means that we've defined a new method with the same name but a different signature. Constructor methods are commonly overloaded. For example, the `Bicycle` class defined in the previous section provides three constructors: `Bicycle()` defined in lines 5-7; `Bicycle(int)` defined in lines 9-11 and `Bicycle(String, String, int)` defined in lines 13-16.

If necessary, the specialized definitions can use the `super` keyword to access the functionality implemented in the superclass methods being overridden. This can be done using the following syntax.

```
super.superclassMethod(argumentList);
```

This allows the subclass to augment the functionality of the superclass's definition of the inherited method.

As an example in the vehicle domain, a programmer might want to have a specialized `toString()` method for the Bicycle class that provides more information than the `toString()` method it inherits from the Vehicle class discussed in Section 13.3.1. This method can be defined as follows.

```
public String toString() {
      return "Bicycle: " + super.toString() + "\n\tgears: " + getGearCount();
}
```

Given this definition overriding the inherited method, we get the following behavior.

Code:

```
Bicycle feltAR5 = new Bicycle("Felt", "AR5", 30);
System.out.println(feltAR5);
```

Output:

```
      Bicycle: Felt AR5
            gears: 30
```

As you recall, the original `toString()` method inherited the Vehicle class would have simply printed out “Felt AR5”. That `toString()` method couldn’t possibly add the string “Bicycle:” as shown here because it can’t know which of the subclasses it is working for. It could be a bicycle, or it could be a skateboard, car, jet or some new descendant that a programmer has chosen to implement. Only the `Bicycle` class can make this assumption. On the other hand, the `Bicycle` class would like to reuse the basic features provided by the `Vehicle` class’s `toString()` in combination with additional, bicycle-specific information. To access this functionality, the overridden version of `toString()` calls the method it is overriding by saying `super.toString()`.

This feature works recursively as well. Rewriting the `Car` and `PoweredVehicle` `toString()` methods to take advantage of this approach is left as an exercise for the reader.

13.3.6. Revisiting the Example

Applying the techniques described in this section provides the basis we need to implement consistent definitions of figure classes such as rectangle, ellipses and lines without resorting to redundant code. The class structure that we will implement can be visualized as follows.

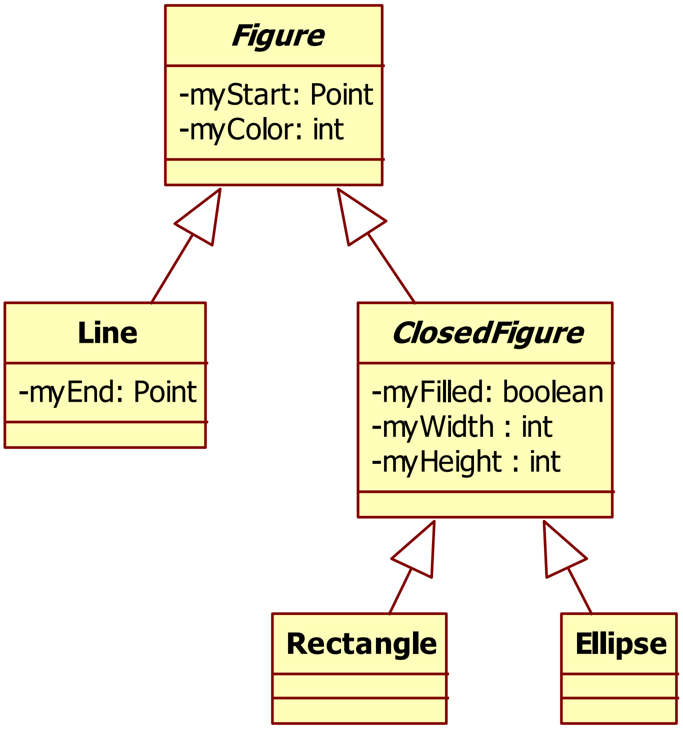


Figure will be the root class and will provide features supporting the figure's color and its "start" point, where the start point for a line is its first point, for a rectangle is it upper left point and for an ellipse is its center point. Closed figures have a width and height, and can be either filled or unfilled. Definitions for these classes are as follows.

Figure.java

```java
class Figure {

    private Point myStart;
    private int myColor;

    public Figure() {
        myStart = new Point(0, 0);
        myColor = 0;
    }

    public Figure(Point start) {
        myStart = start;
        myColor = 0;
    }

    public Figure(Point start, int color) {
        myStart = start;
        myColor = color;
    }

    public Point getStart() {
        return myStart;
    }

    public int getColor() {
        return myColor;
    }

    public void setColor(int color) {
        myColor = color;
    }
}
```

`Figure` is a basic class providing features for a starting point and color.

Line.java

```java
class Line extends Figure {

    private Point myEnd;

    public Line(Point start, int color) {
        super(start, color);
        myEnd = start;
    }

    public Line(Point start, Point end, int color) {
        super(start, color);
        myEnd = end;
    }
}
```

Line extends Figure, adding support for an end point not shared by the other figure classes.

ClosedFigure.java

```
class ClosedFigure extends Figure {

      private int myWidth, myHeight;
      private boolean myFilled;

      public ClosedFigure() {
            myWidth = myHeight = 0;
            myFilled = false;
      }

      public ClosedFigure(Point start, int color, int width, int height,
                          boolean filled) {
            super(start, color);
            myWidth = width;
            myHeight = height;
            myFilled = filled;
      }

      public int getWidth() {
            return myWidth;
      }
      public void setWidth(int width) {
            myWidth = width;
      }

      public int getHeight() {
            return myHeight;
      }

      public void setHeight(int height) {
            myHeight = height;
      }

      public boolean getFilled() {
            return myFilled;
      }
}
```

ClosedFigure bundles those features shared by all closed figures, including rectangles and ellipses.

Rectangle.java

```
class Rectangle extends ClosedFigure {

      public Rectangle(Point start, int width, int height, int color,
                       boolean filled) {
            super(start, color, width, height, filled);
      }

      public Rectangle(Point start, Point end, int color, boolean filled) {
            super(start, color, end.x - start.x, end.y - start.y, filled);
      }

}
```

Rectangle extends ClosedFigure with a constructor that automatically converts from a start-point-end-point characterization of a rectangle to the start-point-width-height characterization required by ClosedFigure. This isn't a particularly exciting at this point; the interesting part comes later in the chapter when we add a render() method that draws the rectangle on the canvas.

With these basic figure classes in place, we can write code as follows:

Code:

```
Rectangle myRectangle = new Rectangle(new Point(10, 10),
                                      new Point(280, 280),
                                      false);
System.out.println(myRectangle);
System.out.println(myRectangle.getFilled());
System.out.println(myRectangle.getColor());
```

Output:

```
c13oop.text.simpledraw.simpledraw1.Rectangle@9304b1
false
0
```

This code segment declares a non-filled Rectangle object, myRectangle, with the given start and end point. It then prints the myRectangle object, which uses the default toString() method from the Object class, and the filled and color settings. Note how the default toString() method prints the class name (and package) and an unintelligible memory address value. We could have improved this point, but these figure classes are designed to be drawn on a canvas, not printed to a console, so we won't bother to override the toString() method. Doing so is left as an exercise for the reader, as is the implementation of the Ellipse class, which is very similar to the Rectangle class.

13.4. Polymorphism

Where inheritance allows subclasses to share features, *polymorphism* allows subclasses to distinguish themselves from one another. Given that in Greek, *poly* means "many" and *morph* means "form", the term polymorphism is used to describe the situation in which a single statement can take on different definitions. This chapter describes how to implement polymorphic behavior in Java.

13.4.1. Declarations and Inheritance

Suppose that we write

```
Vehicle aVehicle = new Bicycle();
```

Because aVehicle is declared as a Vehicle and a Bicycle object is a Vehicle, this is a legal statement. A variable declared as an object of class C can store a reference to any object whose class is a descendant of C.

In contrast, the opposite statement

```
Bicycle aBicycle = new Vehicle();     // ERROR!
```

is not valid because while a Bicycle object is a Vehicle object, the reverse in not true. All bicycles are vehicles, but not all vehicles are bicycles.

This asymmetry has consequences not only for declarations and initializations, but also for method binding. Given that aVehicle is declared as a Vehicle object, Java cannot be certain that it will have access to the Bicycles class's definition of getGearCount(), in spite of the fact that it is initialized to a new Bicycle object. For all we know, aVehicle could be reassigned to a new Skateboard object, which doesn't provide a definition for getGearCount(). Thus, the method invocation

```
aVehicle.getGearCount()     // ERROR!
```

produces a compiler error. getGearCount() is defined only for objects declared to be of type Bicycle, not for objects declared to be of type Vehicle.

13.4.2. Dynamic Binding

Our Vehicle and Bicycle classes currently provide definitions of the toString() method, which we repeat here for convenience.

Vehicle.java

```java
class Vehicle {

      // instance variables, constructors, accessors and mutators...

      public String toString() {
            return getBrand() + " " + getModel();
      }

}
```

Bicycle.java

```java
class Bicycle extends Vehicle {

     // instance variables, constructors, accessors and mutators...
      public String toString() {
            return "Bicycle: " + super.toString() +
                        "\n\tgears: " + getGearCount();
      }

}
```

The Vehicle class provides a more general definition, which the Bicycle class overrides with a bicycle-specific version. Given these definitions, consider the following code segment.

Code:

```java
Vehicle aVehicle = new Bicycle("Trek", "7.4FX", 27);
System.out.println(aVehicle);
```

Output:

```
Bicycle: Trek 7.4FX
      gears: 27
```

In this case, Java cannot be certain at compile time which definition of the `toString()` method should be invoked. Both the `Vehicle` class and the `Bicycle` class provide one. In cases like this, Java determines the appropriate definition to invoke at run time based not on the *declared type* of `aVehicle` but rather on the *actual type* of the object referred to by `aVehicle`. If `aVehicle` refers to a `Bicycle` object, then the `Bicycle` version is invoked; if `aVehicle` refers to a `Vehicle` object, then the `Vehicle` version is invoked. In this case, the specialized `Bicycle` version is invoked and we get the bicycle-specific output shown above.

This determination is known as *binding*, that is, choosing a particular definition of `toString()` to invoke. Bindings made at run time are known as *dynamic* bindings. This is an example of polymorphic behavior because the invocation of `toString()` in this situation can invoke any one of potentially many definitions of that method.

Java's dynamic binding mechanism works as follows. Given a method `m()` invoked on an object of class `C`, if there is a definition of `m()` in `C`, then invoke that method definition. Otherwise, move to `C`'s parent class and search there, proceeding up the class hierarchy until a definition is found.

13.4.3. Abstract Methods and Classes

Imagine now that rather than overriding an existing method like `toString()`, you wanted to add a new method definition for Vehicle objects, say a method that returns the sort of movement that the vehicle object implements. For example, bicycles "cycle" and skateboards "skate". We could do this by defining a `getLocomotion()` method for each of the `Vehicle` subclasses. For `Bicycle`, this method could be implemented as follows:

```
public String getLocomotion() {
      return "cycle";
}
```

Given similar definitions for `Skateboard`, `Car` and `Jet`, suppose that we would like to implement an array of `Vehicle` objects and print their forms of motion as follows.

```
Vehicle[] vehicles = new Vehicle[2];
vehicles[0] = new Bicycle("Trek", "7.4FX", 27);
vehicles[1] = new Skateboard("Ally", "Rocket", 31.5);

for (int i = 0; i < vehicles.length; i++) {
      System.out.println(vehicles[i].getLocomotion());
}
```

This code declares an array of two `Vehicle` objects and initializes each entry to a different subclass of `Vehicle`. It then loops through those vehicle objects printing the form of motion for each. The logic seems fine, but, unfortunately, the invocation of `getLocomotion()` produces a compiler error indicating that the locomotion method is not defined for the `Vehicle` class.

We could consider implementing a generic version of `getLocomotion()` in the `Vehicle` class that the subclasses can override as appropriate – we've seen this approach work with `toString` – but Java provides an alternative approach for such situations based on abstract methods.

An *abstract method* declares but does not define a method. It is specified using the `abstract` modifier as follows.

```
abstract returnType methodIdentifier(parameterList);
```

This declaration is just like the method definitions we've used to this point except that it opens with the `abstract` modifier and ends with a `;` rather than a full method definition. The default designation for methods is *concrete* meaning that they must provide a method definition. Declaring an abstract method in a class `C` has the following consequences:

- Class `C` must also be declared as an abstract class as follows:

  ```
  abstract class C { … }
  ```

  This indicates that objects of type `C` cannot be created using `new`. Doing so would make little sense given that there is no definition of the abstract method(s) it contains and thus the objects would not know how to invoke that method.

- All concrete subclasses of `C` must either implement `C`'s abstract method(s) or inherit them from some other subclass of `C`. This is a sensible requirement because we can make an object of concrete types, so they must have definitions for all their methods.

One useful feature provided by abstract methods is that it can be used to implement the `getLocomotion()` method described above. We can augment the `Vehicle` and `Bicycle` classes as follows.

Vehicle.java

```
abstract class Vehicle {

     // instance variables, constructors, accessors and mutators...

    public abstract String getLocomotion();

}
```

Bicycle.java

```
class Bicycle extends Vehicle {

    // instance variables, constructors, accessors and mutators...

    public String getLocomotion() {
        return "cycle";
    }

}
```

Note that Vehicle now includes an abstract definition of getLocomotion() in line 5. This can be read as a sort of “promissory note” indicating that all concrete subclasses of Vehicle must implement the getLocomotion() method. Note also that Vehicle is now declared to be an abstract class, which means that programmers can no longer create new Vehicle objects using new Vehicle(). This not a sacrifice because it doesn’t really make any sense to declare a “generic” Vehicle object that isn’t going to be initialized to either a Car, Jet or other subclass of Vehicle.

We can make similar modifications to the other subclasses of Vehicle: Skateboard, Car and Jet will get their own concrete definitions of getLocomotion(), Skateboard returning “skate”, Car returning “drive”, etc. PoweredVehicle must become an abstract class like Vehicle but otherwise remains unchanged; it cannot define getLocomotion() and thus simple inherits the abstract definition from Vehicle. Given these modifications, which are left as an exercise for the reader, we can execute this expanded version of the code segment shown above.

Code:

```
Vehicle[] vehicles = new Vehicle[4];
vehicles[0] = new Bicycle("Trek", "7.4FX", 27);
vehicles[1] = new Skateboard("Ally", "Rocket", 31.5);
vehicles[2] = new Car("Volkswagon", "Golf", "gasoline", "1.8 Liter");
vehicles[3] = new Jet("Lear", "LJ45", "jet fuel", 2);

for (int i = 0; i < vehicles.length; i++) {
      System.out.println(vehicles[i].getLocomotion());
}
```

Output:

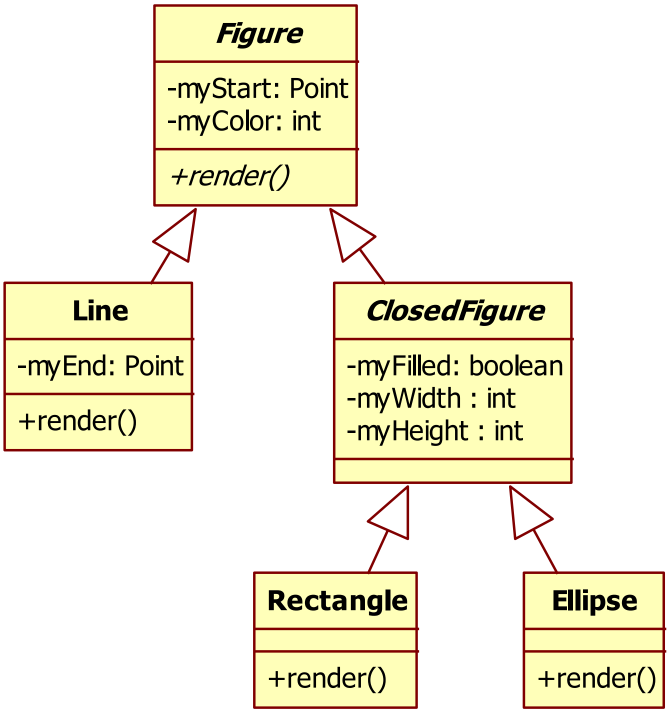
```
cycle
skate
drive
fly
```

The polymorphic call to getLocomotion() no longer produces a compiler error. There is an abstract declaration of the getLocomotion() method in the Vehicle class so all its concrete subclasses are required to have access to a full definition of that method, either by defining one themselves or by inheriting one from a superclass.

As the for loop executes, Java will bind the appropriate definition of getLocomotion() based on the actual type of the object in the vehicles array. In this output, the Bicycle version returns “cycle”, the Skateboard version returns “skate”, the Car version returns “drive” and the Jet version returns “fly”.

13.4.4. Revisiting the Example

For the next iteration of the chapter example, we’d like to actually be able to draw the figures on a canvas, which requires that we implement a render() method for each of the concrete figure classes, i.e., Line, Rectangle and Ellipse. There will be a unique definition of render() for each concrete figure type, and we'd like to be able to create a list of `Figure` objects and bind the correct definition of `render()` for each list entry. To do this, we will augment the class structure as follows.



In this revised structure, the class hierarchy is still the same, but we've added an abstract *`render()`* method declaration, shown in italics in the `Figure` class box, and concrete `render()` method definitions to each of the concrete subclasses, shown in normal font in `Line`, `Rectangle` and `Ellipse`. As a consequence of this change, we've also made the `Figure` and `ClosedFigure` classes abstract.

Figure.java

```
abstract class Figure {

      // instance variables, constructors, accessors and mutators...

      public abstract void render(PApplet p);

}
```

Line.java

```
class Line extends Figure {

      // instance variables, constructors, accessors and mutators...

      public void render(PApplet p) {
            p.stroke(getColor());
            p.line(getStart().x, getStart().y, myEnd.x, myEnd.y);
      }
```

ClosedFigure.java

```
abstract class ClosedFigure extends Figure {

      // This remains unchanged.

}
```

Rectangle.java

```
public class Rectangle extends ClosedFigure {

      // instance variables, constructors, accessors and mutators...

      public void render(PApplet p) {
            p.stroke(getColor());
            if (getFilled()) {
                  p.fill(getColor());
            } else {
                  p.noFill();
            }
            p.rect(getStart().x, getStart().y, getWidth(), getHeight());
      }
}
```

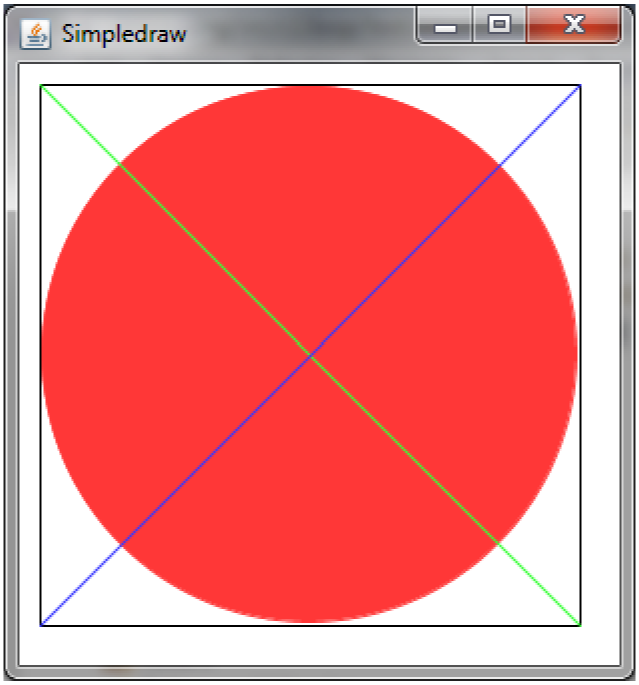
Given this model definition, we can implement a PApplet-based GUI application that creates and draws a list of figures on the canvas. The implementation has a standard PApplet-based GUI controller that we will not discuss here. It follows the simple pattern for encapsulating Processing applications set in Chapter 11. We focus instead on the PApplet panel. This class implements the canvas and creates a list of figure objects, as shown here in `SimpledrawPanel.java`.

SimpledrawPanel.java

```
public class SimpledrawPanel extends PApplet {

      private final int BACKGROUND_COLOR = color(255),
                        WIDTH = 300, HEIGHT = WIDTH;

      private ArrayList<Figure> myFigures;

      public SimpledrawPanel() {
            myFigures = new ArrayList<Figure>();
            myFigures.add(new Rectangle(new Point(10, 10),
                                        new Point(280, 280),
                                        color(0), false));
            myFigures.add(new Ellipse(new Point(11, 11),
                                      new Point(278, 278),
                                      color(255, 55, 55), true));
            myFigures.add(new Line(new Point(10, 10),
                                   new Point(280, 280),
                                   color(55, 255, 55)));
            myFigures.add(new Line(new Point(280, 10),
                                   new Point(10, 280),
                                   color(55, 55, 255)));
      }
23
24          public void setup() {
25                size(WIDTH, HEIGHT);
26                background(BACKGROUND_COLOR);
27                smooth();
28                noLoop();
29          }
30
31          public void draw() {
32                for (int i = 0; i < myFigures.size(); i++) {
33                      myFigures.get(i).render(this);
34                }
35          }
36    }
```

In this implementation, the Panel defines `myFigures`, an `ArrayList` of `Figure` objects, and hard-codes the insertion of a `Rectangle` object, an `Ellipse` object and two `Line` objects (see lines 9-21). The `draw()` method includes a simple for-loop that renders each of the figures in the list using the polymorphic `render()` method defined above. The program works regardless of the number and type of the figure objects added to the list.

The output is as follows.



This output displays the four hard-coded figures rendered by `SimpledrawPanel.java`.

13.5. The Example Revisited

As a final enhancement to the Simpledraw application, we will upgrade the system to support user-directed figure-drawing as described in Section 13.1. The changes to support this application are largely centered in the GUI code but there are some changes to the `Figure` hierarchy as well. A sample output of the program is shown here.

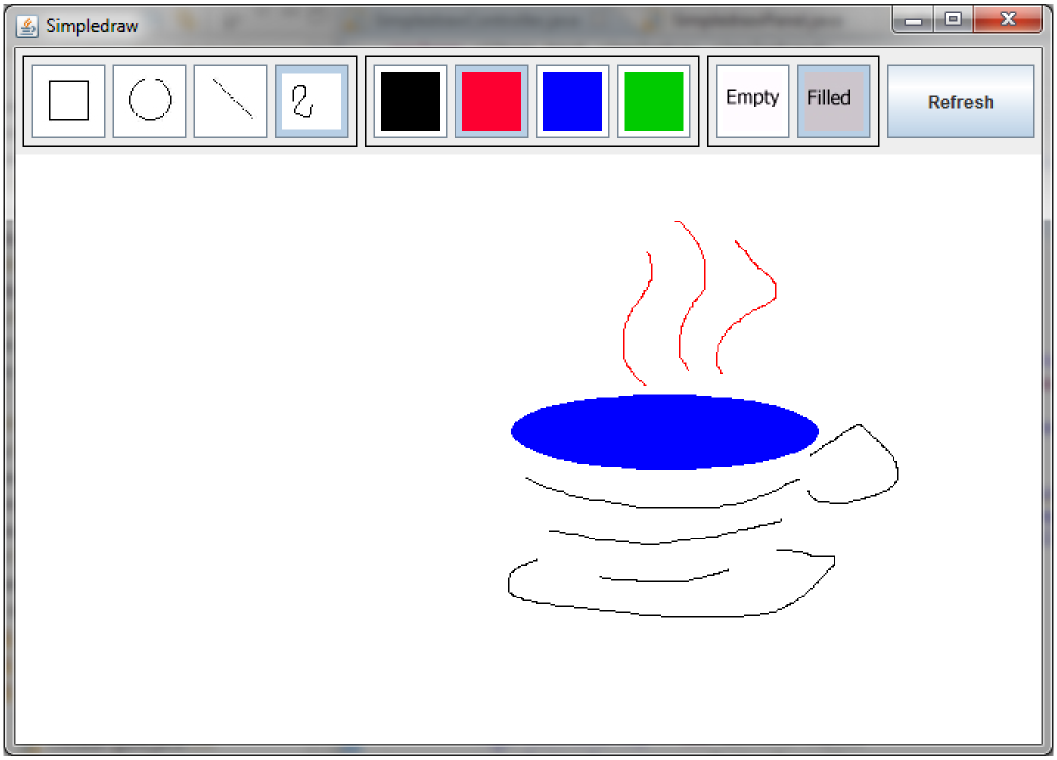


Figure 13-3. Simpledraw

The user is allowed to choose any figure from the figure button panel on the upper left, thus setting the figure model of the interface. They can also choose a color from the color button panel and a filled/no-filled status from the fill button panel to set the color and fill mode of the interface. This figure shown above has one filled ellipse and a number of colored "doodle" lines.

The code for this application is too large to repeat verbatim here, so this section will focus instead on interesting new aspects of the implementation.

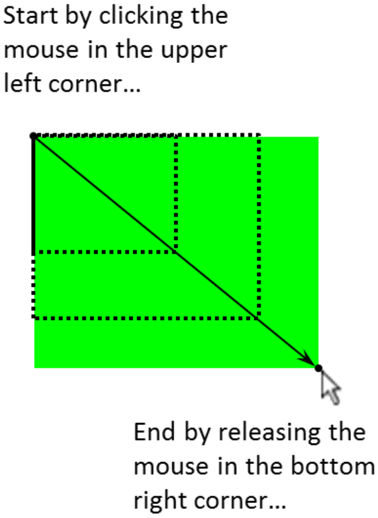

Start by clicking the mouse in the upper left corner...
End by releasing the mouse in the bottom right corner...

Figure 13-2. Interactively specifying a rectangle

13.5.1. Specifying the Figures Interactively

One interesting aspect of this application is that it allows its users to interactively specify new figures. Figure 13-2 illustrates the process by which users specify a rectangle: they click in the upper left, drag the mouse diagonally across the rectangle and then release the mouse in the lower right. As the user is doing this, the interface shows the current state of the rectangle as it is being drawn (illustrated by the dotted rectangles in the figure).

This feature is implemented in the SimpledrawPanel as follows.

SimpledrawPanel.java (selected methods)

```
1   /**
2    * Create a new figure object of the appropriate type and initialize its
3    * start point, color and filled status.
4    */
5   public void mousePressed() {
6         if (myFigureMode.equals("rectangle")) {
7               myCurrentFigure = new Rectangle(new Point(mouseX, mouseY),
8                                                myColorMode, myFilledMode);
9         } else if (myFigureMode.equals("ellipse")) {
10              myCurrentFigure = new Ellipse(new Point(mouseX, mouseY),
11                                             myColorMode, myFilledMode);
12        } else if (myFigureMode.equals("doodle")) {
13              myCurrentFigure = new Doodle(new Point(mouseX, mouseY),
14                                            myColorMode);
15        } else {
16              myCurrentFigure = new Line(new Point(mouseX, mouseY),
17                                          myColorMode);
18        }
19  }
20
21  /**
22   * Erase the previous temporary figure, change the end point to the
23   * current mouse position and redraw the temporary figure.
24   */
25  public void mouseDragged() {
26        int figureColor = myCurrentFigure.getColor();
27        myCurrentFigure.setColor(BACKGROUND_COLOR);
28        myCurrentFigure.render(this);
29        myCurrentFigure.setColor(figureColor);
30        myCurrentFigure.updatePoint(new Point(mouseX, mouseY));
31        myCurrentFigure.render(this);
32  }
33
34  /**
35   * Add the new figure just created to the myFigures list.
36   */
37  public void mouseReleased() {
38        myFigures.add(myCurrentFigure);
39  }
```

These three methods implement the mouse-based interaction that creates figures as shown in Figure 13-2. In `mouseDragged()` note:

- Lines 27-28 set the drawing color to the background color and redraw the figure in order to erase the temporary figure image.
- Line 30 updates the second point of the figure definition, e.g., the lower right point for a rectangle, to the current mouse position before redrawing the temporary figure image.

The update point method is another abstract method defined in the Figure class and implemented in all the concrete subclasses. For the Rectangle class, the definition is as follows:

```
public void updatePoint(Point p) {
        myWidth = p.x - myStart.x;
        myHeight = p.y - myStart.y;
}
```

This method receives a point from the calling program and computes the width and height of the rectangle based on the start and end coordinates.

The user is allowed to create as many figures and they would like, in any order. Thus, `myFigures` is implemented as an `ArrayList`, and the event-handler for the "Refresh" button is implemented as follows.

```
public void refresh() {
        for (int i = 0; i < myFigures.size(); i++) {
                myFigures.get(i).render(this);
        }

}
```

This redraws all the figures using the polymorphic behavior described in the previous section.

The implementation of the `Doodle` figure constructed in lines 12-14 is left as an exercise for the reader. It is implemented as an `ArrayList` of points signaled by the `mouseDragged()` method.

13.5.2. Implementing Modal Button Panels

One interesting aspect of the interface is the use of button groups. Figure 13-3 shows three button groups: the figure buttons (i.e., rectangle, ellipse, line and doodle); the color buttons (i.e., black, red, blue and green); and the fill status buttons (i.e., unfilled and filled). These groups are implemented so that only one button is shown to be pressed at any time. This is used to indicate the interface's current figure mode.

The figure button group is implemented using the following code in `SimpledrawController.java`.

SimpledrawController.java

```
public class SimpledrawController extends JFrame {

        // constants...

        private JPanel buttonPanel, figureButtonPanel;
        private JButton refreshButton;
        private JToggleButton rectangleButton;
        private ButtonGroup figureButtonGroup;

       // other buttons, panels and groups...

        public SimpledrawController() throws Exception {
                setTitle("Simpledraw");
                setDefaultCloseOperation(EXIT_ON_CLOSE);

                figureButtonGroup = new ButtonGroup();
                figureButtonPanel = new JPanel();
```

```
            figureButtonPanel.setBorder(
                           BorderFactory.createLineBorder(Color.black));

            // other buttons and button groups...

            buttonPanel = new JPanel();
            buttonPanel.add(figureButtonPanel);

            rectangleButton = makeButton("Rectangle", figureButtonGroup,
                                         figureButtonPanel,
                                         new RectangleButtonListener());
            rectangleButton.setSelected(true);

            drawingPanel = new SimpledrawPanel("rectangle", "black", false);
            drawingPanel.init();

            add(buttonPanel, BorderLayout.NORTH);
            add(drawingPanel, BorderLayout.CENTER);
      }

      /**
       * This method constructs a new button.
       *
       * @param buttonType
       *             the type of the button (e.g., "Rectangle", "Ellipse")
                    - This is used to get the button's icon.
       * @param group
       *             the button group in which the button should be placed
       * @param panel
       *             the panel in which the button should be placed
       * @param listener
       *             the action listener for the button
       * @return the new button object
       */
      private JToggleButton makeButton(String buttonType,
                                       ButtonGroup group, JPanel panel,
                  ActionListener listener) {
            JToggleButton result = new JToggleButton(
                              new ImageIcon(PATH + buttonType + ".jpg"));
            result.addActionListener(listener);
            result.setActionCommand(buttonType);
            result.setPreferredSize(DEFAULT_BUTTON_DIMENSION);
            result.setBackground(Color.white);
            group.add(result);
            panel.add(result);
            return result;
      }

      class RectangleButtonListener implements ActionListener {
            @Override
            public void actionPerformed(ActionEvent e) {
                  drawingPanel.setFigureMode("rectangle");
            }
      }

      // other action listener classes and main() method here...
}
```

Note the following in this code:

- All the figure buttons are constructed by `makeButton()` (lines 53-65), which combines the button-creation code that is used for each of the buttons.
- makeButton() adds each button to the appropriate button group (line 62), which ensures that only one button is shown as selected.
- makeButton() adds each button to the appropriate button panel (line 63), which ensures that the button is displayed in the appropriate place.
- Each button listener, e.g., the `RectangleButtonListener` shown in lines 67-72, sets the appropriate mode in the `SimpledrawPanel` class.