13.1 Introduction

Key Point

A superclass defines common behavior for related subclasses. An interface can be used to define common behavior for classes (including unrelated classes).

problem

interface

You can use the **java.util.Arrays.sort** method to sort an array of numbers or strings. Can you apply the same **sort** method to sort an array of geometric objects? In order to write such code, you have to know about interfaces. An *interface* is for defining common behavior for classes (including unrelated classes). Before discussing interfaces, we introduce a closely related subject: abstract classes.

13.2 Abstract Classes

Key Point

An abstract class cannot be used to create objects. An abstract class can contain abstract methods, which are implemented in concrete subclasses.

VideoNote

Abstract GeometricObject class

In the inheritance hierarchy, classes become more specific and concrete *with each new subclass*. If you move from a subclass back up to a superclass, the classes become more general and less specific. Class design should ensure that a superclass contains common features of its subclasses. Sometimes a superclass is so abstract that it cannot be used to create any specific instances. Such a class is referred to as an *abstract class*.

abstract class

abstract method

abstract modifier

In Chapter 11, **GeometricObject** was defined as the superclass for **Circle** and **Rectangle**. **GeometricObject** models common features of geometric objects. Both **Circle** and **Rectangle** contain the **getArea()** and **getPerimeter()** methods for computing the area and perimeter of a circle and a rectangle. Since you can compute areas and perimeters for all geometric objects, it is better to define the **getArea()** and **getPerimeter()** methods in the **GeometricObject** class. However, these methods cannot be implemented in the **GeometricObject** class, because their implementation depends on the specific type of geometric object. Such methods are referred to as *abstract methods* and are denoted using the **abstract** modifier in the method header. After you define the methods in **GeometricObject**, it becomes an abstract class. Abstract classes are denoted using the **abstract** modifier in the class header. In UML graphic notation, the names of abstract classes and their abstract methods are italicized, as shown in Figure 13.1. Listing 13.1 gives the source code for the new **GeometricObject** class.

Listing 13.1 GeometricObject.java

abstract class

```
public abstract class GeometricObject {
  private String color = "white";
  private boolean filled;
  private java.util.Date dateCreated;

  /** Construct a default geometric object */
  protected GeometricObject() {
    dateCreated = new java.util.Date();
  }

  /** Construct a geometric object with color and filled value */
  protected GeometricObject(String color, boolean filled) {
    dateCreated = new java.util.Date();
    this.color = color;
    this.filled = filled;
  }

  /** Return color */
  public String getColor() {
    return color;
```

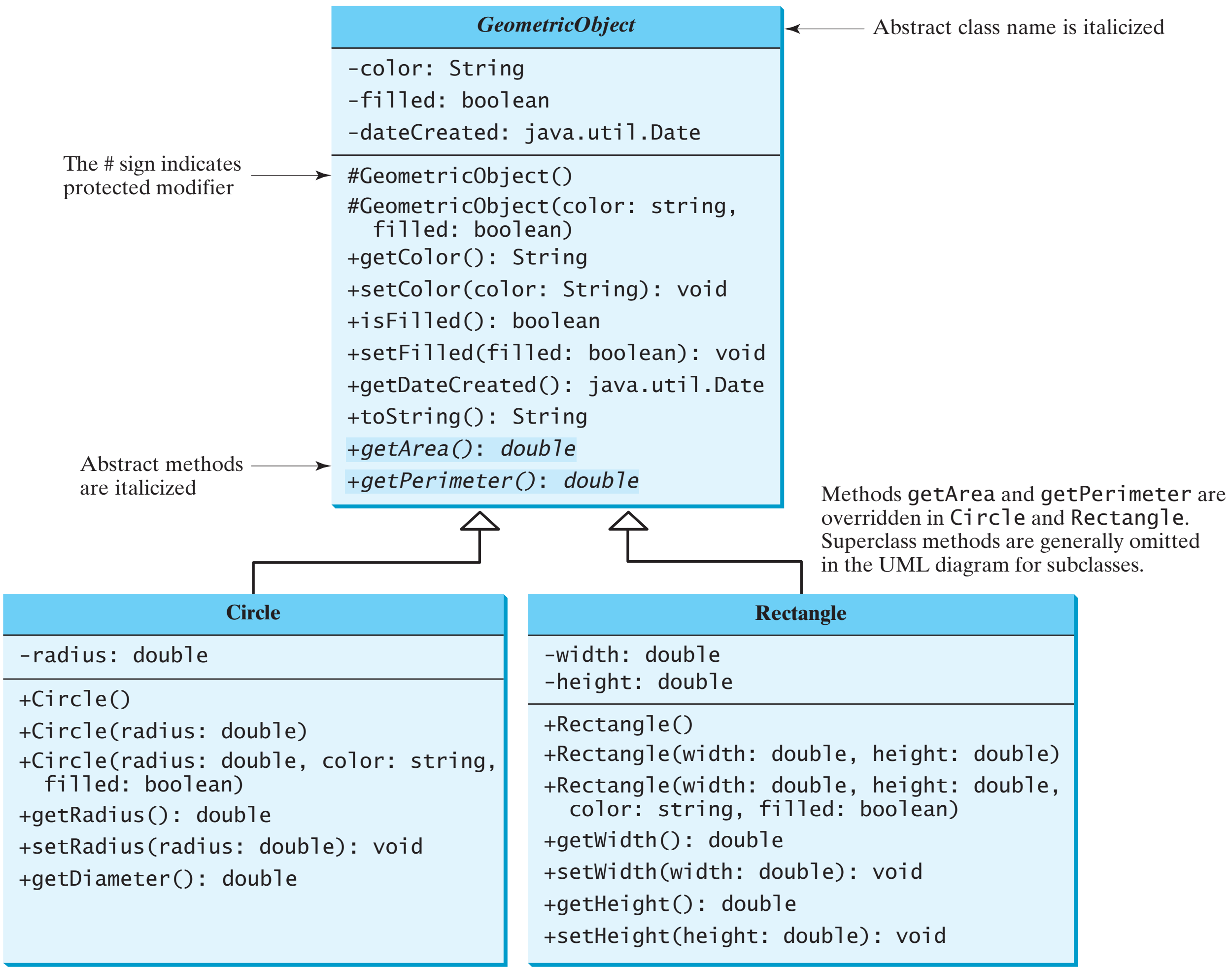

GeometricObject
-color: String
-filled: boolean
-dateCreated: java.util.Date
#GeometricObject()
#GeometricObject(color: string, filled: boolean)
+getColor(): String
+setColor(color: String): void
+isFilled(): boolean
+setFilled(filled: boolean): void
+getDateCreated(): java.util.Date
+toString(): String
+getArea(): double
+getPerimeter(): double
Abstract class name is italicized
The # sign indicates protected modifier
Abstract methods are italicized
Methods getArea and getPerimeter are overridden in Circle and Rectangle. Superclass methods are generally omitted in the UML diagram for subclasses.
Circle
-radius: double
+Circle()
+Circle(radius: double)
+Circle(radius: double, color: string, filled: boolean)
+getRadius(): double
+setRadius(radius: double): void
+getDiameter(): double
Rectangle
-width: double
-height: double
+Rectangle()
+Rectangle(width: double, height: double)
+Rectangle(width: double, height: double, color: string, filled: boolean)
+getWidth(): double
+setWidth(width: double): void
+getHeight(): double
+setHeight(height: double): void

FIGURE 13.1 The new `GeometricObject` class contains abstract methods.

```
  }

  /** Set a new color */
  public void setColor(String color) {
    this.color = color;
  }

  /** Return filled. Since filled is boolean,
   *  the get method is named isFilled */
  public boolean isFilled() {
    return filled;
  }

  /** Set a new filled */
  public void setFilled(boolean filled) {
    this.filled = filled;
  }

  /** Get dateCreated */
  public java.util.Date getDateCreated() {
    return dateCreated;
  }
```

abstract method

abstract method

```java

  @Override
  public String toString() {
    return "created on " + dateCreated + "\ncolor: " + color +
      " and filled: " + filled;
  }

  /** Abstract method getArea */
  public abstract double getArea();

  /** Abstract method getPerimeter */
  public abstract double getPerimeter();
}
```

Abstract classes are like regular classes, but you cannot create instances of abstract classes using the **new** operator. An abstract method is defined without implementation. Its implementation is provided by the subclasses. A class that contains abstract methods must be defined as abstract.

why protected constructor?

The constructor in the abstract class is defined as protected, because it is used only by subclasses. When you create an instance of a concrete subclass, its superclass's constructor is invoked to initialize data fields defined in the superclass.

The **GeometricObject** abstract class defines the common features (data and methods) for geometric objects and provides appropriate constructors. Because you don't know how to compute areas and perimeters of geometric objects, **getArea()** and **getPerimeter()** are defined as abstract methods. These methods are implemented in the subclasses. The implementation of **Circle** and **Rectangle** is the same as in Listings 13.2 and 13.3, except that they extend the **GeometricObject** class defined in this chapter. You can see the complete code for these two programs from www.cs.armstrong.edu/liang/intro10e/html/Circle.html and www.cs.armstrong.edu/liang/intro10e/html/Rectangle.html, respectively.

implement Circle
implement Rectangle

LISTING 13.2 Circle.java

extends abstract GeometricObject

```java
public class Circle extends GeometricObject {
  // Same as lines 3-48 in Listing 11.2, so omitted
}
```

LISTING 13.3 Rectangle.java

extends abstract GeometricObject

```java
public class Rectangle extends GeometricObject {
  // Same as lines 3-51 in Listing 11.3, so omitted
}
```

13.2.1 Why Abstract Methods?

You may be wondering what advantage is gained by defining the methods **getArea()** and **getPerimeter()** as abstract in the **GeometricObject** class. The example in Listing 13.4 shows the benefits of defining them in the **GeometricObject** class. The program creates two geometric objects, a circle and a rectangle, invokes the **equalArea** method to check whether they have equal areas, and invokes the **displayGeometricObject** method to display them.

LISTING 13.4 TestGeometricObject.java

create a circle
create a rectangle

```java
public class TestGeometricObject {
  /** Main method */
  public static void main(String[] args) {
    // Create two geometric objects
    GeometricObject geoObject1 = new Circle(5);
    GeometricObject geoObject2 = new Rectangle(5, 3);
```

```
 7
 8       System.out.println("The two objects have the same area? " +
 9         equalArea(geoObject1, geoObject2));
10
11       // Display circle
12       displayGeometricObject(geoObject1);
13
14       // Display rectangle
15       displayGeometricObject(geoObject2);
16     }
17
18     /** A method for comparing the areas of two geometric objects */
19     public static boolean equalArea(GeometricObject object1,
20         GeometricObject object2) {
21       return object1.getArea() == object2.getArea();
22     }
23
24     /** A method for displaying a geometric object */
25     public static void displayGeometricObject(GeometricObject object) {
26       System.out.println();
27       System.out.println("The area is " + object.getArea());
28       System.out.println("The perimeter is " + object.getPerimeter());
29     }
30   }
```

equalArea

displayGeometricObject

```
The two objects have the same area? false

The area is 78.53981633974483
The perimeter is 31.41592653589793

The area is 13.0
The perimeter is 16.0
```

The methods **getArea()** and **getPerimeter()** defined in the **GeometricObject** class are overridden in the **Circle** class and the **Rectangle** class. The statements (lines 5–6)

```
GeometricObject geoObject1 = new Circle(5);
GeometricObject geoObject2 = new Rectangle(5, 3);
```

create a new circle and rectangle and assign them to the variables **geoObject1** and **geoObject2**. These two variables are of the **GeometricObject** type.

When invoking **equalArea(geoObject1, geoObject2)** (line 9), the **getArea()** method defined in the **Circle** class is used for **object1.getArea()**, since **geoObject1** is a circle, and the **getArea()** method defined in the **Rectangle** class is used for **object2.getArea()**, since **geoObject2** is a rectangle.

Similarly, when invoking **displayGeometricObject(geoObject1)** (line 12), the methods **getArea()** and **getPerimeter()** defined in the **Circle** class are used, and when invoking **displayGeometricObject(geoObject2)** (line 15), the methods **getArea** and **getPerimeter** defined in the **Rectangle** class are used. The JVM dynamically determines which of these methods to invoke at runtime, depending on the actual object that invokes the method.

Note that you could not define the **equalArea** method for comparing whether two geometric objects have the same area if the **getArea** method were not defined in **GeometricObject**. Now you have seen the benefits of defining the abstract methods in **GeometricObject**.

why abstract methods?

13.2.2 Interesting Points about Abstract Classes

The following points about abstract classes are worth noting:

abstract method in abstract class

- An abstract method cannot be contained in a nonabstract class. If a subclass of an abstract superclass does not implement all the abstract methods, the subclass must be defined as abstract. In other words, in a nonabstract subclass extended from an abstract class, all the abstract methods must be implemented. Also note that abstract methods are nonstatic.

object cannot be created from abstract class

- An abstract class cannot be instantiated using the `new` operator, but you can still define its constructors, which are invoked in the constructors of its subclasses. For instance, the constructors of `GeometricObject` are invoked in the `Circle` class and the `Rectangle` class.

abstract class without abstract method

- A class that contains abstract methods must be abstract. However, it is possible to define an abstract class that doesn't contain any abstract methods. In this case, you cannot create instances of the class using the `new` operator. This class is used as a base class for defining subclasses.

concrete method overridden to be abstract

- A subclass can override a method from its superclass to define it as abstract. This is *very unusual*, but it is useful when the implementation of the method in the superclass becomes invalid in the subclass. In this case, the subclass must be defined as abstract.

superclass of abstract class may be concrete

- A subclass can be abstract even if its superclass is concrete. For example, the `Object` class is concrete, but its subclasses, such as `GeometricObject`, may be abstract.

abstract class as type

- You cannot create an instance from an abstract class using the `new` operator, but an abstract class can be used as a data type. Therefore, the following statement, which creates an array whose elements are of the `GeometricObject` type, is correct.

```
GeometricObject[] objects = new GeometricObject[10];
```

You can then create an instance of `GeometricObject` and assign its reference to the array like this:

```
objects[0] = new Circle();
```

Check Point

13.1 Which of the following classes defines a legal abstract class?

```
class A {
  abstract void unfinished() {
  }
}
```

(a)

```
public class abstract A {
  abstract void unfinished();
}
```

(b)

```
class A {
  abstract void unfinished();
}
```

(c)

```
abstract class A {
  protected void unfinished();
}
```

(d)

```
abstract class A {
  abstract void unfinished();
}
```

(e)

```
abstract class A {
  abstract int unfinished();
}
```

(f)

13.2 The `getArea()` and `getPerimeter()` methods may be removed from the `GeometricObject` class. What are the benefits of defining `getArea()` and `getPerimeter()` as abstract methods in the `GeometricObject` class?

13.3 True or false?

a. An abstract class can be used just like a nonabstract class except that you cannot use the `new` operator to create an instance from the abstract class.

b. An abstract class can be extended.

c. A subclass of a nonabstract superclass cannot be abstract.

d. A subclass cannot override a concrete method in a superclass to define it as abstract.

e. An abstract method must be nonstatic.

13.3 Case Study: the Abstract **Number** Class

`Number` is an abstract superclass for numeric wrapper classes, `BigInteger`, and `BigDecimal`.

Key Point

Section 10.7 introduced numeric wrapper classes and Section 10.9 introduced the `BigInteger` and `BigDecimal` classes. These classes have common methods `byteValue()`, `shortValue()`, `intValue()`, `longValue()`, `floatValue()`, and `doubleValue()` for returning a `byte`, `short`, `int`, `long`, `float`, and `double` value from an object of these classes. These common methods are actually defined in the `Number` class, which is a superclass for the numeric wrapper classes, `BigInteger`, and `BigDecimal`, as shown in Figure 13.2.

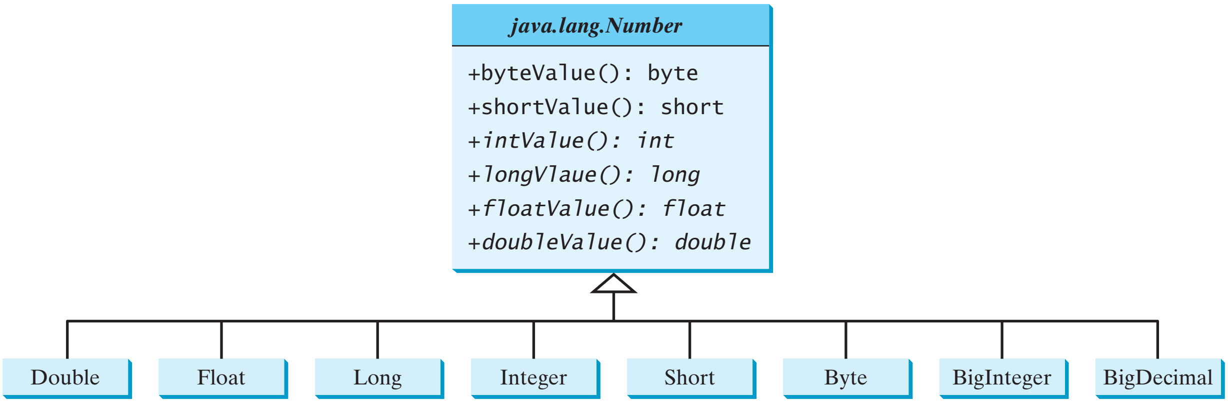


FIGURE 13.2 The `Number` class is an abstract superclass for `Double`, `Float`, `Long`, `Integer`, `Short`, `Byte`, `BigInteger` and `BigDecimal`.

Since the `intValue()`, `longValue()`, `floatValue()`, and `doubleValue()` methods cannot be implemented in the `Number` class, they are defined as abstract methods in the `Number` class. The `Number` class is therefore an abstract class. The `byteValue()` and `shortValue()` method are implemented from the `intValue()` method as follows:

```
public byte byteValue() {
  return (byte)intValue();
}

public short shortValue() {
  return (short)intValue();
}
```

With **Number** defined as the superclass for the numeric classes, we can define methods to perform common operations for numbers. Listing 13.5 gives a program that finds the largest number in a list of **Number** objects.

LISTING 13.5 LargestNumbers.java

create an array list

add number to list

invoke getLargestNumber

doubleValue

```
 1  import java.util.ArrayList;
 2  import java.math.*;
 3
 4  public class LargestNumbers {
 5    public static void main(String[] args) {
 6      ArrayList<Number> list = new ArrayList<>();
 7      list.add(45); // Add an integer
 8      list.add(3445.53); // Add a double
 9      // Add a BigInteger
10      list.add(new BigInteger("3432323234344343101"));
11      // Add a BigDecimal
12      list.add(new BigDecimal("2.0909090989091343433344343"));
13
14      System.out.println("The largest number is " +
15        getLargestNumber(list));
16    }
17
18    public static Number getLargestNumber(ArrayList<Number> list) {
19      if (list == null || list.size() == 0)
20        return null;
21
22      Number number = list.get(0);
23      for (int i = 1; i < list.size(); i++)
24        if (number.doubleValue() < list.get(i).doubleValue())
25          number = list.get(i);
26
27      return number;
28    }
29  }
```

```
The largest number is 3432323234344343101
```

The program creates an **ArrayList** of **Number** objects (line 6). It adds an **Integer** object, a **Double** object, a **BigInteger** object, and a **BigDecimal** object to the list (lines 7–12). Note that **45** is automatically converted into an **Integer** object and added to the list in line 7 and that **3445.53** is automatically converted into a **Double** object and added to the list in line 8 using autoboxing.

Invoking the **getLargestNumber** method returns the largest number in the list (line 15). The **getLargestNumber** method returns **null** if the list is **null** or the list size is **0** (lines 19–20). To find the largest number in the list, the numbers are compared by invoking their **doubleValue()** method (line 24). The **doubleValue()** method is defined in the **Number** class and implemented in the concrete subclass of **Number**. If a number is an **Integer** object, the **Integer**'s **doubleValue()** is invoked. If a number is a **BigDecimal** object, the **BigDecimal**'s **doubleValue()** is invoked.

If the **doubleValue()** method were not defined in the **Number** class, you will not be able to find the largest number among different types of numbers using the **Number** class.

Check Point

13.4 Why do the following two lines of code compile but cause a runtime error?

```
Number numberRef = new Integer(0);
Double doubleRef = (Double)numberRef;
```

13.5 Why do the following two lines of code compile but cause a runtime error?

```
Number[] numberArray = new Integer[2];
numberArray[0] = new Double(1.5);
```

13.6 Show the output of the following code.

```
public class Test {
  public static void main(String[] args) {
    Number x = 3;
    System.out.println(x.intValue());
    System.out.println(x.doubleValue());
  }
}
```

13.7 What is wrong in the following code? (Note that the `compareTo` method for the `Integer` and `Double` classes was introduced in Section 10.7.)

```
public class Test {
  public static void main(String[] args) {
    Number x = new Integer(3);
    System.out.println(x.intValue());
    System.out.println(x.compareTo(new Integer(4)));
  }
}
```

13.8 What is wrong in the following code?

```
public class Test {
  public static void main(String[] args) {
    Number x = new Integer(3);
    System.out.println(x.intValue());
    System.out.println((Integer)x.compareTo(new Integer(4)));
  }
}
```

13.4 Case Study: Calendar and GregorianCalendar

Key Point

`GregorianCalendar` is a concrete subclass of the abstract class `Calendar`.

VideoNote

`Calendar` and `GregorianCalendar` classes

An instance of `java.util.Date` represents a specific instant in time with millisecond precision. `java.util.Calendar` is an abstract base class for extracting detailed calendar information, such as the year, month, date, hour, minute, and second. Subclasses of `Calendar` can implement specific calendar systems, such as the Gregorian calendar, the lunar calendar, and the Jewish calendar. Currently, `java.util.GregorianCalendar` for the Gregorian calendar is supported in Java, as shown in Figure 13.3. The `add` method is abstract in the `Calendar` class, because its implementation is dependent on a concrete calendar system.

abstract `add` method

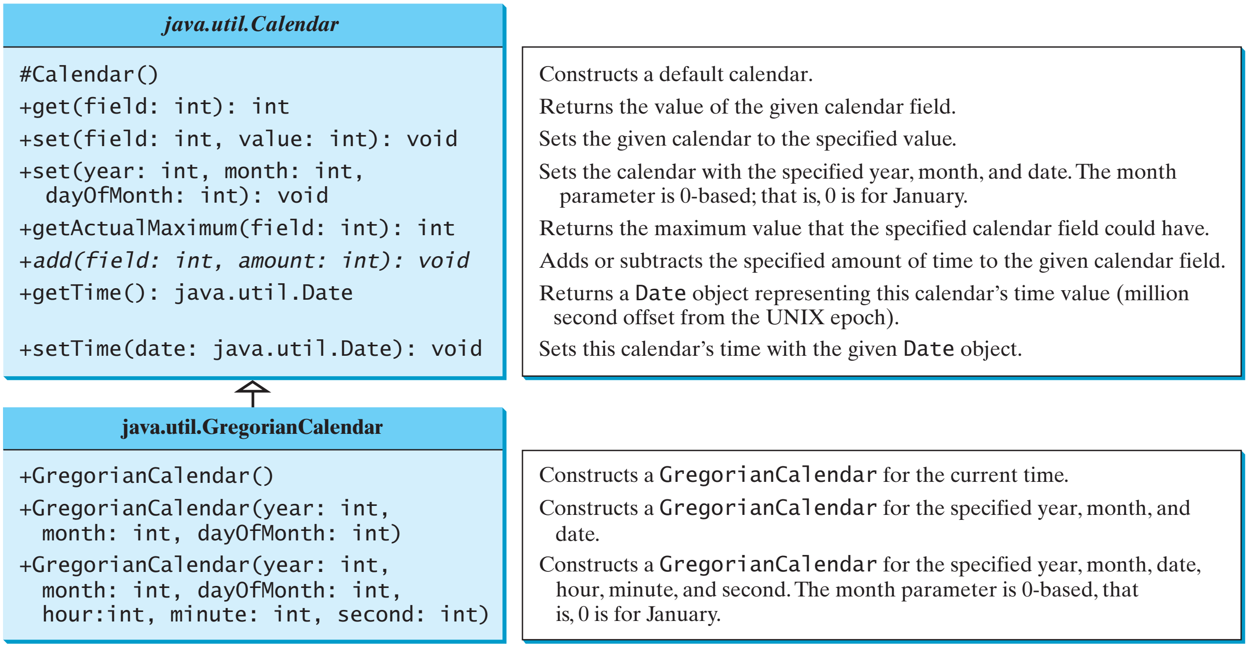
construct calendar

You can use `new GregorianCalendar()` to construct a default `GregorianCalendar` with the current time and `new GregorianCalendar(year, month, date)` to construct a `GregorianCalendar` with the specified `year`, `month`, and `date`. The `month` parameter is `0` based—that is, `0` is for January.

`get(field)`

The `get(int field)` method defined in the `Calendar` class is useful for extracting the date and time information from a `Calendar` object. The fields are defined as constants, as shown in Table 13.1.

Listing 13.6 gives an example that displays the date and time information for the current time.


java.util.Calendar
#Calendar()
+get(field: int): int
+set(field: int, value: int): void
+set(year: int, month: int, dayOfMonth: int): void
+getActualMaximum(field: int): int
+add(field: int, amount: int): void
+getTime(): java.util.Date
+setTime(date: java.util.Date): void
java.util.GregorianCalendar
+GregorianCalendar()
+GregorianCalendar(year: int, month: int, dayOfMonth: int)
+GregorianCalendar(year: int, month: int, dayOfMonth: int, hour:int, minute: int, second: int)

Constructs a default calendar.

Returns the value of the given calendar field.

Sets the given calendar to the specified value.

Sets the calendar with the specified year, month, and date. The month parameter is 0-based; that is, 0 is for January.

Returns the maximum value that the specified calendar field could have.

Adds or subtracts the specified amount of time to the given calendar field.

Returns a Date object representing this calendar's time value (million second offset from the UNIX epoch).

Sets this calendar's time with the given Date object.

Constructs a GregorianCalendar for the current time.

Constructs a GregorianCalendar for the specified year, month, and date.

Constructs a GregorianCalendar for the specified year, month, date, hour, minute, and second. The month parameter is 0-based, that is, 0 is for January.

Figure 13.3 The abstract Calendar class defines common features of various calendars.

Table 13.1 Field Constants in the Calendar Class

Constant	*Description*
YEAR	The year of the calendar.
MONTH	The month of the calendar, with 0 for January.
DATE	The day of the calendar.
HOUR	The hour of the calendar (12-hour notation).
HOUR_OF_DAY	The hour of the calendar (24-hour notation).
MINUTE	The minute of the calendar.
SECOND	The second of the calendar.
DAY_OF_WEEK	The day number within the week, with 1 for Sunday.
DAY_OF_MONTH	Same as DATE.
DAY_OF_YEAR	The day number in the year, with 1 for the first day of the year.
WEEK_OF_MONTH	The week number within the month, with 1 for the first week.
WEEK_OF_YEAR	The week number within the year, with 1 for the first week.
AM_PM	Indicator for AM or PM (0 for AM and 1 for PM).

Listing 13.6 TestCalendar.java

```java
import java.util.*;

public class TestCalendar {
  public static void main(String[] args) {
    // Construct a Gregorian calendar for the current date and time
    Calendar calendar = new GregorianCalendar();
    System.out.println("Current time is " + new Date());
    System.out.println("YEAR: " + calendar.get(Calendar.YEAR));
```

calendar for current time

extract fields in calendar

```
    System.out.println("MONTH: " + calendar.get(Calendar.MONTH));
    System.out.println("DATE: " + calendar.get(Calendar.DATE));
    System.out.println("HOUR: " + calendar.get(Calendar.HOUR));
    System.out.println("HOUR_OF_DAY: " +
      calendar.get(Calendar.HOUR_OF_DAY));
    System.out.println("MINUTE: " + calendar.get(Calendar.MINUTE));
    System.out.println("SECOND: " + calendar.get(Calendar.SECOND));
    System.out.println("DAY_OF_WEEK: " +
      calendar.get(Calendar.DAY_OF_WEEK));
    System.out.println("DAY_OF_MONTH: " +
      calendar.get(Calendar.DAY_OF_MONTH));
    System.out.println("DAY_OF_YEAR: " +
      calendar.get(Calendar.DAY_OF_YEAR));
    System.out.println("WEEK_OF_MONTH: " +
      calendar.get(Calendar.WEEK_OF_MONTH));
    System.out.println("WEEK_OF_YEAR: " +
      calendar.get(Calendar.WEEK_OF_YEAR));
    System.out.println("AM_PM: " + calendar.get(Calendar.AM_PM));

    // Construct a calendar for September 11, 2001
    Calendar calendar1 = new GregorianCalendar(2001, 8, 11);
    String[] dayNameOfWeek = {"Sunday", "Monday", "Tuesday", "Wednesday",
      "Thursday", "Friday", "Saturday"};
    System.out.println("September 11, 2001 is a " +
      dayNameOfWeek[calendar1.get(Calendar.DAY_OF_WEEK) - 1]);
  }
}
```

create a calendar

```
Current time is Sun Nov 27 17:48:15 EST 2011
YEAR: 2011
MONTH: 10
DATE: 27
HOUR: 5
HOUR_OF_DAY: 17
MINUTE: 48
SECOND: 15
DAY_OF_WEEK: 1
DAY_OF_MONTH: 27
DAY_OF_YEAR: 331
WEEK_OF_MONTH: 5
WEEK_OF_YEAR: 49
AM_PM: 1
September 11, 2001 is a Tuesday
```

set(field, value)

The set(int field, value) method defined in the Calendar class can be used to set a field. For example, you can use calendar.set(Calendar.DAY_OF_MONTH, 1) to set the calendar to the first day of the month.

add(field, amount)

The add(field, value) method adds the specified amount to a given field. For example, add(Calendar.DAY_OF_MONTH, 5) adds five days to the current time of the calendar. add(Calendar.DAY_OF_MONTH, -5) subtracts five days from the current time of the calendar.

getActualMaximum(field)

To obtain the number of days in a month, use calendar.getActualMaximum(Calendar.DAY_OF_MONTH). For example, if the calendar were for March, this method would return 31.

setTime(date)
getTime()

You can set a time represented in a **Date** object for the **calendar** by invoking **calendar.setTime(date)** and retrieve the time by invoking **calendar.getTime()**.

Check Point

13.9 Can you create a **Calendar** object using the **Calendar** class?

13.10 Which method in the **Calendar** class is abstract?

13.11 How do you create a **Calendar** object for the current time?

13.12 For a **Calendar** object **c**, how do you get its year, month, date, hour, minute, and second?

13.5 Interfaces

Key Point

An interface is a class-like construct that contains only constants and abstract methods.

VideoNote
The concept of interface

In many ways an interface is similar to an abstract class, but its intent is to specify common behavior for objects of related classes or unrelated classes. For example, using appropriate interfaces, you can specify that the objects are comparable, edible, and/or cloneable.

To distinguish an interface from a class, Java uses the following syntax to define an interface:

```
modifier interface InterfaceName {
  /** Constant declarations */
  /** Abstract method signatures */
}
```

Here is an example of an interface:

```
public interface Edible {
  /** Describe how to eat */
  public abstract String howToEat();
}
```

An interface is treated like a special class in Java. Each interface is compiled into a separate bytecode file, just like a regular class. You can use an interface more or less the same way you use an abstract class. For example, you can use an interface as a data type for a reference variable, as the result of casting, and so on. As with an abstract class, you cannot create an instance from an interface using the **new** operator.

You can use the **Edible** interface to specify whether an object is edible. This is accomplished by letting the class for the object implement this interface using the **implements** keyword. For example, the classes **Chicken** and **Fruit** in Listing 13.7 (lines 20, 39) implement the **Edible** interface. The relationship between the class and the interface is known as *interface inheritance*. Since interface inheritance and class inheritance are essentially the same, we will simply refer to both as *inheritance*.

interface inheritance

Listing 13.7 TestEdible.java

```
 1  public class TestEdible {
 2    public static void main(String[] args) {
 3      Object[] objects = {new Tiger(), new Chicken(), new Apple()};
 4      for (int i = 0; i < objects.length; i++) {
 5        if (objects[i] instanceof Edible)
 6          System.out.println(((Edible)objects[i]).howToEat());
 7
 8        if (objects[i] instanceof Animal) {
 9          System.out.println(((Animal)objects[i]).sound());
10        }
11      }
12    }
13  }
```

```
14
15  abstract class Animal {
16    /** Return animal sound */
17    public abstract String sound();
18  }
19
20  class Chicken extends Animal implements Edible {
21    @Override
22    public String howToEat() {
23      return "Chicken: Fry it";
24    }
25
26    @Override
27    public String sound() {
28      return "Chicken: cock-a-doodle-doo";
29    }
30  }
31
32  class Tiger extends Animal {
33    @Override
34    public String sound() {
35      return "Tiger: RROOAARR";
36    }
37  }
38
39  abstract class Fruit implements Edible {
40    // Data fields, constructors, and methods omitted here
41  }
42
43  class Apple extends Fruit {
44    @Override
45    public String howToEat() {
46      return "Apple: Make apple cider";
47    }
48  }
49
50  class Orange extends Fruit {
51    @Override
52    public String howToEat() {
53      return "Orange: Make orange juice";
54    }
55  }
```

Animal class

implements Edible

howToEat()

Tiger class

implements Edible

Apple class

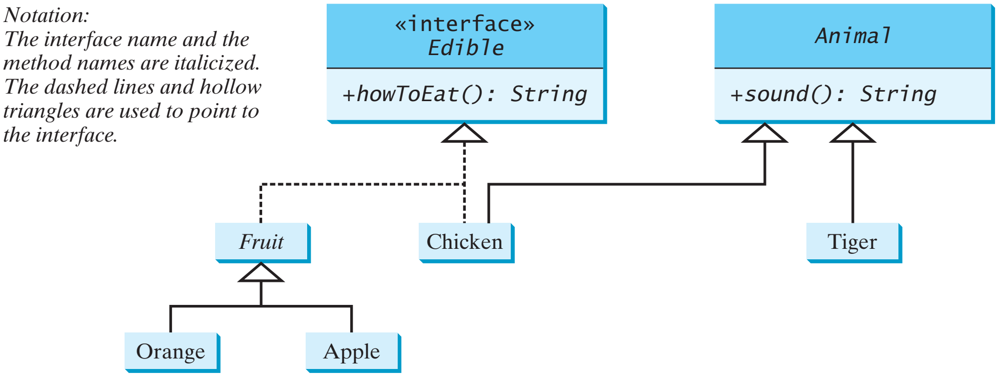
Orange class

```
Tiger: RROOAARR
Chicken: Fry it
Chicken: cock-a-doodle-doo
Apple: Make apple cider
```

This example uses several classes and interfaces. Their inheritance relationship is shown in Figure 13.4.

The **Animal** class defines the **sound** method (line 17). It is an abstract method and will be implemented by a concrete animal class.

The **Chicken** class implements **Edible** to specify that chickens are edible. When a class implements an interface, it implements all the methods defined in the interface with the exact signature and return type. The **Chicken** class implements the **howToEat** method (lines 22–24). **Chicken** also extends **Animal** to implement the **sound** method (lines 27–29).



Notation:
The interface name and the method names are italicized. The dashed lines and hollow triangles are used to point to the interface.

FIGURE 13.4 `Edible` is a supertype for `Chicken` and `Fruit`. `Animal` is a supertype for `Chicken` and `Tiger`. `Fruit` is a supertype for `Orange` and `Apple`.

The `Fruit` class implements `Edible`. Since it does not implement the `howToEat` method, `Fruit` must be denoted as `abstract` (line 39). The concrete subclasses of `Fruit` must implement the `howToEat` method. The `Apple` and `Orange` classes implement the `howToEat` method (lines 45, 52).

The `main` method creates an array with three objects for `Tiger`, `Chicken`, and `Apple` (line 3), and invokes the `howToEat` method if the element is edible (line 6) and the `sound` method if the element is an animal (line 9).

common behavior

In essence, the `Edible` interface defines common behavior for edible objects. All edible objects have the `howToEat` method.

omit modifiers

Note

Since all data fields are `public static final` and all methods are `public abstract` in an interface, Java allows these modifiers to be omitted. Therefore the following interface definitions are equivalent:

```
public interface T {
  public static final int K = 1;

  public abstract void p();
}
```

Equivalent

```
public interface T {
  int K = 1;

  void p();
}
```

Check Point

13.13 Suppose `A` is an interface. Can you create an instance using `new A()`?

13.14 Suppose `A` is an interface. Can you declare a reference variable `x` with type `A` like this?

```
A x;
```

13.15 Which of the following is a correct interface?

```
interface A {
  void print() { };
}
```

(a)

```
abstract interface A extends I1, I2 {
  abstract void print() { };
}
```

(b)

```
abstract interface A {
  print();
}
```

(c)

```
interface A {
  void print();
}
```

(d)

13.16 Show the error in the following code:

```
interface A {
  void m1();
}

class B implements A {
  void m1() {
    System.out.println("m1");
  }
}
```

13.6 The **Comparable** Interface

The **Comparable** *interface defines the* **compareTo** *method for comparing objects.*

Key Point

Suppose you want to design a generic method to find the larger of two objects of the same type, such as two students, two dates, two circles, two rectangles, or two squares. In order to accomplish this, the two objects must be comparable, so the common behavior for the objects must be comparable. Java provides the **Comparable** interface for this purpose. The interface is defined as follows:

java.lang.Comparable

```
// Interface for comparing objects, defined in java.lang
package java.lang;

public interface Comparable<E> {
  public int compareTo(E o);
}
```

The **compareTo** method determines the order of this object with the specified object **o** and returns a negative integer, zero, or a positive integer if this object is less than, equal to, or greater than **o**.

The **Comparable** interface is a generic interface. The generic type **E** is replaced by a concrete type when implementing this interface. Many classes in the Java library implement **Comparable** to define a natural order for objects. The classes **Byte**, **Short**, **Integer**, **Long**, **Float**, **Double**, **Character**, **BigInteger**, **BigDecimal**, **Calendar**, **String**, and **Date** all implement the **Comparable** interface. For example, the **Integer**, **BigInteger**, **String**, and **Date** classes are defined as follows in the Java API:

```
public class Integer extends Number
    implements Comparable<Integer> {
  // class body omitted

  @Override
  public int compareTo(Integer o) {
    // Implementation omitted
  }
}
```

```
public class BigInteger extends Number
    implements Comparable<BigInteger> {
  // class body omitted

  @Override
  public int compareTo(BigInteger o) {
    // Implementation omitted
  }
}
```

```
public class String extends Object
    implements Comparable<String> {
  // class body omitted

  @Override
  public int compareTo(String o) {
    // Implementation omitted
  }
}
```

```
public class Date extends Object
    implements Comparable<Date> {
  // class body omitted

  @Override
  public int compareTo(Date o) {
    // Implementation omitted
  }
}
```

Thus, numbers are comparable, strings are comparable, and so are dates. You can use the **compareTo** method to compare two numbers, two strings, and two dates. For example, the following code

```
1  System.out.println(new Integer(3).compareTo(new Integer(5)));
2  System.out.println("ABC".compareTo("ABE"));
3  java.util.Date date1 = new java.util.Date(2013, 1, 1);
4  java.util.Date date2 = new java.util.Date(2012, 1, 1);
5  System.out.println(date1.compareTo(date2));
```

displays

```
-1
-2
 1
```

Line 1 displays a negative value since **3** is less than **5**. Line 2 displays a negative value since **ABC** is less than **ABE**. Line 5 displays a positive value since **date1** is greater than **date2**.

Let **n** be an **Integer** object, **s** be a **String** object, and **d** be a **Date** object. All the following expressions are **true**.

```
n instanceof Integer
n instanceof Object
n instanceof Comparable
```

```
s instanceof String
s instanceof Object
s instanceof Comparable
```

```
d instanceof java.util.Date
d instanceof Object
d instanceof Comparable
```

Since all **Comparable** objects have the **compareTo** method, the **java.util.Arrays.sort(Object[])** method in the Java API uses the **compareTo** method to compare and sorts the objects in an array, provided that the objects are instances of the **Comparable** interface. Listing 13.8 gives an example of sorting an array of strings and an array of **BigInteger** objects.

Listing 13.8 SortComparableObjects.java

create an array

sort the array

create an array

sort the array

```
import java.math.*;

public class SortComparableObjects {
  public static void main(String[] args) {
    String[] cities = {"Savannah", "Boston", "Atlanta", "Tampa"};
    java.util.Arrays.sort(cities);
    for (String city: cities)
      System.out.print(city + " ");
    System.out.println();

    BigInteger[] hugeNumbers = {new BigInteger("2323231092923992"),
      new BigInteger("432232323239292"),
      new BigInteger("54623239292")};
    java.util.Arrays.sort(hugeNumbers);
    for (BigInteger number: hugeNumbers)
      System.out.print(number + " ");
  }
}
```

```
Atlanta Boston Savannah Tampa
54623239292 432232323239292 2323231092923992
```

The program creates an array of strings (line 5) and invokes the `sort` method to sort the strings (line 6). The program creates an array of `BigInteger` objects (lines 11–13) and invokes the `sort` method to sort the `BigInteger` objects (line 14).

You cannot use the `sort` method to sort an array of `Rectangle` objects, because `Rectangle` does not implement `Comparable`. However, you can define a new rectangle class that implements `Comparable`. The instances of this new class are comparable. Let this new class be named `ComparableRectangle`, as shown in Listing 13.9.

LISTING 13.9 ComparableRectangle.java

```java
public class ComparableRectangle extends Rectangle
    implements Comparable<ComparableRectangle> {
  /** Construct a ComparableRectangle with specified properties */
  public ComparableRectangle(double width, double height) {
    super(width, height);
  }

  @Override // Implement the compareTo method defined in Comparable
  public int compareTo(ComparableRectangle o) {
    if (getArea() > o.getArea())
      return 1;
    else if (getArea() < o.getArea())
      return -1;
    else
      return 0;
  }

  @Override // Implement the toString method in GeometricObject
  public String toString() {
    return super.toString() + " Area: " + getArea();
  }
}
```

implements `Comparable`

implement `compareTo`

implement `toString`

`ComparableRectangle` extends `Rectangle` and implements `Comparable`, as shown in Figure 13.5. The keyword `implements` indicates that `ComparableRectangle` inherits all the constants from the `Comparable` interface and implements the methods in the interface. The `compareTo` method compares the areas of two rectangles. An instance of `ComparableRectangle` is also an instance of `Rectangle`, `GeometricObject`, `Object`, and `Comparable`.

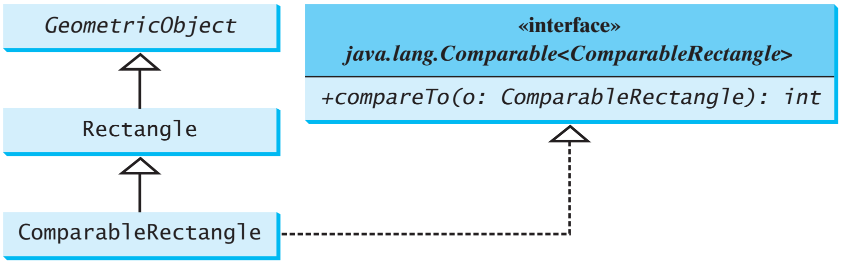

GeometricObject
Rectangle
ComparableRectangle
«interface»
java.lang.Comparable<ComparableRectangle>
+compareTo(o: ComparableRectangle): int

FIGURE 13.5 `ComparableRectangle` extends `Rectangle` and implements `Comparable`.

You can now use the sort method to sort an array of ComparableRectangle objects, as in Listing 13.10.

LISTING 13.10 SortRectangles.java

create an array

sort the array

```
public class SortRectangles {
  public static void main(String[] args) {
    ComparableRectangle[] rectangles = {
      new ComparableRectangle(3.4, 5.4),
      new ComparableRectangle(13.24, 55.4),
      new ComparableRectangle(7.4, 35.4),
      new ComparableRectangle(1.4, 25.4)};
    java.util.Arrays.sort(rectangles);
    for (Rectangle rectangle: rectangles) {
      System.out.print(rectangle + " ");
      System.out.println();
    }
  }
}
```

```
Width: 3.4 Height: 5.4 Area: 18.36
Width: 1.4 Height: 25.4 Area: 35.559999999999995
Width: 7.4 Height: 35.4 Area: 261.96
Width: 13.24 Height: 55.4 Area: 733.496
```

benefits of interface

An interface provides another form of generic programming. It would be difficult to use a generic sort method to sort the objects without using an interface in this example, because multiple inheritance would be necessary to inherit Comparable and another class, such as Rectangle, at the same time.

The Object class contains the equals method, which is intended for the subclasses of the Object class to override in order to compare whether the contents of the objects are the same. Suppose that the Object class contains the compareTo method, as defined in the Comparable interface; the sort method can be used to compare a list of *any* objects. Whether a compareTo method should be included in the Object class is debatable. Since the compareTo method is not defined in the Object class, the Comparable interface is defined in Java to enable objects to be compared if they are instances of the Comparable interface. It is strongly recommended (though not required) that compareTo should be consistent with equals. That is, for two objects o1 and o2, o1.compareTo(o2) == 0 if and only if o1.equals(o2) is true.

Check Point

13.17 True or false? If a class implements Comparable, the object of the class can invoke the compareTo method.

13.18 Which of the following is the correct method header for the compareTo method in the String class?

```
public int compareTo(String o)
public int compareTo(Object o)
```

13.19 Can the following code be compiled? Why?

```
Integer n1 = new Integer(3);
Object n2 = new Integer(4);
System.out.println(n1.compareTo(n2));
```

13.20 You can define the **compareTo** method in a class without implementing the **Comparable** interface. What are the benefits of implementing the **Comparable** interface?

13.21 What is wrong in the following code?

```
public class Test {
  public static void main(String[] args) {
    Person[] persons = {new Person(3), new Person(4), new Person(1)};
    java.util.Arrays.sort(persons);
  }
}

class Person {
  private int id;

  Person(int id) {
    this.id = id;
  }
}
```

13.7 The **Cloneable** Interface

The **Cloneable** *interface specifies that an object can be cloned.*

Key Point

Often it is desirable to create a copy of an object. To do this, you need to use the **clone** method and understand the **Cloneable** interface.

An interface contains constants and abstract methods, but the **Cloneable** interface is a special case. The **Cloneable** interface in the **java.lang** package is defined as follows:

java.lang.Cloneable

```
package java.lang;

public interface Cloneable {
}
```

marker interface

This interface is empty. An interface with an empty body is referred to as a *marker interface*. A marker interface does not contain constants or methods. It is used to denote that a class possesses certain desirable properties. A class that implements the **Cloneable** interface is marked cloneable, and its objects can be cloned using the **clone()** method defined in the **Object** class.

Many classes in the Java library (e.g., **Date**, **Calendar**, and **ArrayList**) implement **Cloneable**. Thus, the instances of these classes can be cloned. For example, the following code

```
Calendar calendar = new GregorianCalendar(2013, 2, 1);
Calendar calendar1 = calendar;
Calendar calendar2 = (Calendar)calendar.clone();
System.out.println("calendar == calendar1 is " +
  (calendar == calendar1));
System.out.println("calendar == calendar2 is " +
  (calendar == calendar2));
System.out.println("calendar.equals(calendar2) is " +
  calendar.equals(calendar2));
```

displays

```
calendar == calendar1 is true
calendar == calendar2 is false
calendar.equals(calendar2) is true
```

In the preceding code, line 2 copies the reference of calendar to calendar1, so calendar and calendar1 point to the same Calendar object. Line 3 creates a new object that is the clone of calendar and assigns the new object's reference to calendar2. calendar2 and calendar are different objects with the same contents.

The following code

```
1  ArrayList<Double> list1 = new ArrayList<>();
2  list1.add(1.5);
3  list1.add(2.5);
4  list1.add(3.5);
5  ArrayList<Double> list2 = (ArrayList<Double>)list1.clone();
6  ArrayList<Double> list3 = list1;
7  list2.add(4.5);
8  list3.remove(1.5);
9  System.out.println("list1 is " + list1);
10 System.out.println("list2 is " + list2);
11 System.out.println("list3 is " + list3);
```

displays

```
list1 is [2.5, 3.5]
list2 is [1.5, 2.5, 3.5, 4.5]
list3 is [2.5, 3.5]
```

In the preceding code, line 5 creates a new object that is the clone of list1 and assigns the new object's reference to list2. list2 and list1 are different objects with the same contents. Line 6 copies the reference of list1 to list3, so list1 and list3 point to the same ArrayList object. Line 7 adds 4.5 into list2. Line 8 removes 1.5 from list3. Since list1 and list3 point to the same ArrayList, line 9 and 11 display the same content.

clone arrays

You can clone an array using the clone method. For example, the following code

```
int[] list1 = {1, 2};
int[] list2 = list1.clone();
list1[0] = 7;
list2[1] = 8;
System.out.println("list1 is " + list1[0] + ", " + list1[1]);
System.out.println("list2 is " + list2[0] + ", " + list2[1]);
```

displays

```
list1 is 7, 2
list2 is 1, 8
```

how to implement Cloneable

To define a custom class that implements the Cloneable interface, the class must override the clone() method in the Object class. Listing 13.11 defines a class named House that implements Cloneable and Comparable.

Listing 13.11 House.java

```
public class House implements Cloneable, Comparable<House> {
  private int id;
  private double area;
  private java.util.Date whenBuilt;

  public House(int id, double area) {
    this.id = id;
    this.area = area;
    whenBuilt = new java.util.Date();
  }
11
12     public int getId() {
13       return id;
14     }
15
16     public double getArea() {
17       return area;
18     }
19
20     public java.util.Date getWhenBuilt() {
21       return whenBuilt;
22     }
23
24     @Override /** Override the protected clone method defined in
25       the Object class, and strengthen its accessibility */
26     public Object clone() throws CloneNotSupportedException {
27       return super.clone();
28     }
29
30     @Override // Implement the compareTo method defined in Comparable
31     public int compareTo(House o) {
32       if (area > o.area)
33         return 1;
34       else if (area < o.area)
35         return -1;
36       else
37         return 0;
38     }
39   }
```

This exception is thrown if `House` does not implement `Cloneable`

The `House` class implements the `clone` method (lines 26–28) defined in the `Object` class. The header is:

```
protected native Object clone() throws CloneNotSupportedException;
```

The keyword `native` indicates that this method is not written in Java but is implemented in the JVM for the native platform. The keyword `protected` restricts the method to be accessed in the same package or in a subclass. For this reason, the `House` class must override the method and change the visibility modifier to `public` so that the method can be used in any package. Since the `clone` method implemented for the native platform in the `Object` class performs the task of cloning objects, the `clone` method in the `House` class simply invokes `super.clone()`. The `clone` method defined in the `Object` class may throw `CloneNotSupportedException`.

`CloneNotSupportedException`

The `House` class implements the `compareTo` method (lines 31–38) defined in the `Comparable` interface. The method compares the areas of two houses.

You can now create an object of the `House` class and create an identical copy from it, as follows:

```
House house1 = new House(1, 1750.50);
House house2 = (House)house1.clone();
```

`house1` and `house2` are two different objects with identical contents. The `clone` method in the `Object` class copies each field from the original object to the target object. If the field is of a primitive type, its value is copied. For example, the value of `area` (`double` type) is copied from `house1` to `house2`. If the field is of an object, the reference of the field is copied. For example, the field `whenBuilt` is of the `Date` class, so its reference is copied into `house2`, as shown in Figure 13.6. Therefore, `house1.whenBuilt == house2.whenBuilt` is true, although `house1 == house2` is false. This is referred to as a *shallow copy* rather than a

shallow copy

deep copy

deep copy, meaning that if the field is of an object type, the object's reference is copied rather than its contents.

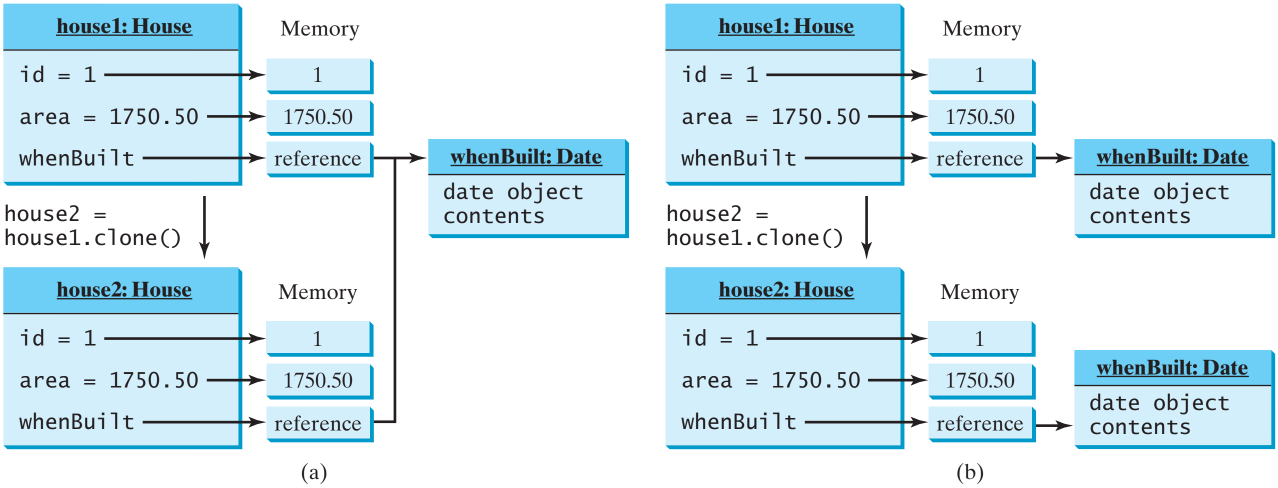


FIGURE 13.6 (a) The default `clone` method performs a shallow copy. (b) The custom `clone` method performs a deep copy.

deep copy

To perform a deep copy for a `House` object, replace the `clone()` method in lines 26–28 with the following code:

```
public Object clone() throws CloneNotSupportedException {
  // Perform a shallow copy
  House houseClone = (House)super.clone();
  // Deep copy on whenBuilt
  houseClone.whenBuilt = (java.util.Date)(whenBuilt.clone());
  return houseClone;
}
```

or

```
public Object clone() {
  try {
    // Perform a shallow copy
    House houseClone = (House)super.clone();
    // Deep copy on whenBuilt
    houseClone.whenBuilt = (java.util.Date)(whenBuilt.clone());
    return houseClone;
  }
  catch (CloneNotSupportedException ex) {
    return null;
  }
}
```

Now if you clone a `House` object in the following code:

```
House house1 = new House(1, 1750.50);
House house2 = (House)house1.clone();
```

`house1.whenBuilt` == `house2.whenBuilt` will be `false`. `house1` and `house2` contain two different `Date` objects, as shown in Figure 13.6b.

Check Point

13.22 Can you invoke the `clone()` method to clone an object if the class for the object does not implement the `java.lang.Cloneable`? Does the `Date` class implement `Cloneable`?

13.23 What would happen if the `House` class (defined in Listing 13.11) did not override the `clone()` method or if `House` did not implement `java.lang.Cloneable`?

13.24 Show the output of the following code:

```
java.util.Date date = new java.util.Date();
java.util.Date date1 = date;
java.util.Date date2 = (java.util.Date)(date.clone());
System.out.println(date == date1);
System.out.println(date == date2);
System.out.println(date.equals(date2));
```

13.25 Show the output of the following code:

```
ArrayList<String> list = new ArrayList<>();
list.add("New York");
ArrayList<String> list1 = list;
ArrayList<String> list2 = (ArrayList<String>)(list.clone());
list.add("Atlanta");
System.out.println(list == list1);
System.out.println(list == list2);
System.out.println("list is " + list);
System.out.println("list1 is " + list1);
System.out.println("list2.get(0) is " + list2.get(0));
System.out.println("list2.size() is " + list2.size());
```

13.26 What is wrong in the following code?

```
public class Test {
  public static void main(String[] args) {
    GeometricObject x = new Circle(3);
    GeometricObject y = x.clone();
    System.out.println(x == y);
  }
}
```

13.8 Interfaces vs. Abstract Classes

A class can implement multiple interfaces, but it can only extend one superclass.

Key Point

An interface can be used more or less the same way as an abstract class, but defining an interface is different from defining an abstract class. Table 13.2 summarizes the differences.

Table 13.2 Interfaces vs. Abstract Classes

	Variables	*Constructors*	*Methods*
Abstract class	No restrictions.	Constructors are invoked by subclasses through constructor chaining. An abstract class cannot be instantiated using the new operator.	No restrictions.
Interface	All variables must be `public static final`.	No constructors. An interface cannot be instantiated using the new operator.	All methods must be public abstract instance methods

single inheritance
multiple inheritance

Java allows only *single inheritance* for class extension but allows *multiple extensions* for interfaces. For example,

```
public class NewClass extends BaseClass
    implements Interface1, ..., InterfaceN {
  ...
}
```

subinterface

An interface can inherit other interfaces using the extends keyword. Such an interface is called a *subinterface*. For example, NewInterface in the following code is a subinterface of Interface1, . . . , and InterfaceN.

```
public interface NewInterface extends Interface1, ... , InterfaceN {
  // constants and abstract methods
}
```

A class implementing NewInterface must implement the abstract methods defined in NewInterface, Interface1, . . . , and InterfaceN. An interface can extend other interfaces but not classes. A class can extend its superclass and implement multiple interfaces.

All classes share a single root, the Object class, but there is no single root for interfaces. Like a class, an interface also defines a type. A variable of an interface type can reference any instance of the class that implements the interface. If a class implements an interface, the interface is like a superclass for the class. You can use an interface as a data type and cast a variable of an interface type to its subclass, and vice versa. For example, suppose that c is an instance of Class2 in Figure 13.7. c is also an instance of Object, Class1, Interface1, Interface1_1, Interface1_2, Interface2_1, and Interface2_2.

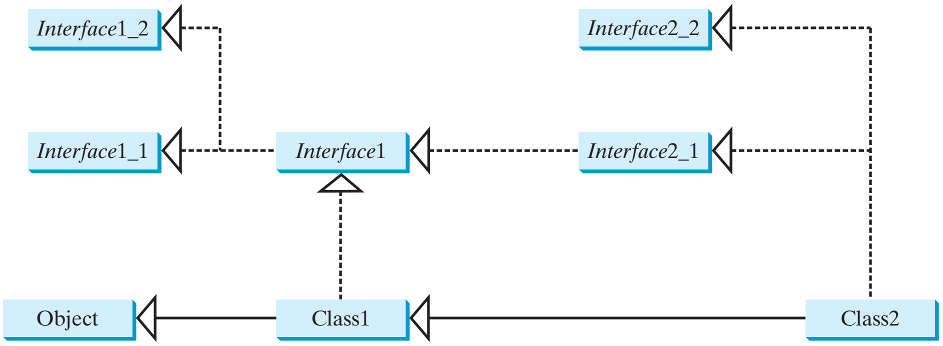


FIGURE 13.7 Class1 implements Interface1; Interface1 extends Interface1_1 and Interface1_2. Class2 extends Class1 and implements Interface2_1 and Interface2_2.

naming convention

Note

Class names are nouns. Interface names may be adjectives or nouns.

Design Guide

is-a relationship
is-kind-of relationship

Abstract classes and interfaces can both be used to specify common behavior of objects. How do you decide whether to use an interface or a class? In general, a *strong is-a relationship* that clearly describes a parent-child relationship should be modeled using classes. For example, Gregorian calendar is a calendar, so the relationship between the class java.util.GregorianCalendar and java.util.Calendar is modeled using class inheritance. A *weak is-a relationship*, also known as an *is-kind-of relationship*, indicates that an object possesses a certain property. A weak is-a relationship can be modeled using interfaces. For example, all strings are comparable, so the String class implements the Comparable interface.

interface preferred

In general, interfaces are preferred over abstract classes because an interface can define a common supertype for unrelated classes. Interfaces are more flexible than classes. Consider the Animal class. Suppose the howToEat method is defined in the Animal class, as follows:

Animal class

```
abstract class Animal {
  public abstract String howToEat();
}
```

Two subclasses of Animal are defined as follows:

Chicken class

```
class Chicken extends Animal {
  @Override
  public String howToEat() {
    return "Fry it";
  }
}
```

Duck class

```
class Duck extends Animal {
  @Override
  public String howToEat() {
    return "Roast it";
  }
}
```

Given this inheritance hierarchy, polymorphism enables you to hold a reference to a Chicken object or a Duck object in a variable of type Animal, as in the following code:

```
public static void main(String[] args) {
  Animal animal = new Chicken();
  eat(animal);

  animal = new Duck();
  eat(animal);
}

public static void eat(Animal animal) {
  animal.howToEat();
}
```

The JVM dynamically decides which howToEat method to invoke based on the actual object that invokes the method.

You can define a subclass of Animal. However, there is a restriction: The subclass must be for another animal (e.g., Turkey).

Interfaces don't have this restriction. Interfaces give you more flexibility than classes, because you don't have to make everything fit into one type of class. You may define the howToEat() method in an interface and let it serve as a common supertype for other classes. For example,

```
public static void main(String[] args) {
  Edible stuff = new Chicken();
  eat(stuff);

  stuff = new Duck();
  eat(stuff);

  stuff = new Broccoli();
  eat(stuff);
}
```

```
public static void eat(Edible stuff) {
  stuff.howToEat();
}
```

`Edible` interface

```
interface Edible {
  public String howToEat();
}
```

`Chicken` class

```
class Chicken implements Edible {
  @Override
  public String howToEat() {
    return "Fry it";
  }
}
```

`Duck` class

```
class Duck implements Edible {
  @Override
  public String howToEat() {
    return "Roast it";
  }
}
```

`Broccoli` class

```
class Broccoli implements Edible {
  @Override
  public String howToEat() {
    return "Stir-fry it";
  }
}
```

To define a class that represents edible objects, simply let the class implement the `Edible` interface. The class is now a subtype of the `Edible` type, and any `Edible` object can be passed to invoke the `howToEat` method.

13.27 Give an example to show why interfaces are preferred over abstract classes.

13.28 Define the terms abstract classes and interfaces. What are the similarities and differences between abstract classes and interfaces?

13.29 True or false?

a. An interface is compiled into a separate bytecode file.

b. An interface can have static methods.

c. An interface can extend one or more interfaces.

d. An interface can extend an abstract class.

e. An abstract class can extend an interface.

13.9 Case Study: The `Rational` Class

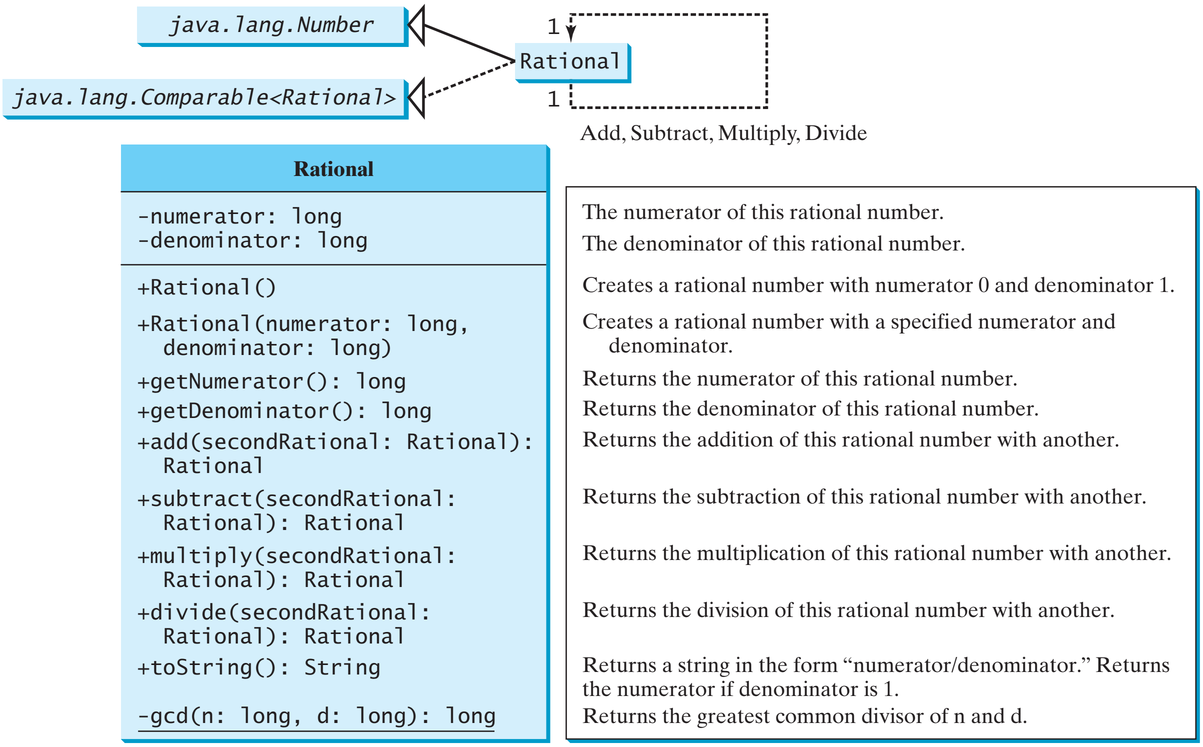
This section shows how to design the `Rational` class for representing and processing rational numbers.

A rational number has a numerator and a denominator in the form `a/b`, where `a` is the numerator and `b` the denominator. For example, `1/3`, `3/4`, and `10/4` are rational numbers.

A rational number cannot have a denominator of `0`, but a numerator of `0` is fine. Every integer `i` is equivalent to a rational number `i/1`. Rational numbers are used in exact computations involving fractions—for example, `1/3 = 0.33333`. . . . This number cannot be precisely represented in floating-point format using either the data type `double` or `float`. To obtain the exact result, we must use rational numbers.

Java provides data types for integers and floating-point numbers, but not for rational numbers. This section shows how to design a class to represent rational numbers.

Since rational numbers share many common features with integers and floating-point numbers, and `Number` is the root class for numeric wrapper classes, it is appropriate to define `Rational` as a subclass of `Number`. Since rational numbers are comparable, the `Rational` class should also implement the `Comparable` interface. Figure 13.8 illustrates the `Rational` class and its relationship to the `Number` class and the `Comparable` interface.



java.lang.Number
java.lang.Comparable<Rational>
Rational
1
1
Add, Subtract, Multiply, Divide

Rational	
-numerator: long	The numerator of this rational number.
-denominator: long	The denominator of this rational number.
+Rational()	Creates a rational number with numerator 0 and denominator 1.
+Rational(numerator: long, denominator: long)	Creates a rational number with a specified numerator and denominator.
+getNumerator(): long	Returns the numerator of this rational number.
+getDenominator(): long	Returns the denominator of this rational number.
+add(secondRational: Rational): Rational	Returns the addition of this rational number with another.
+subtract(secondRational: Rational): Rational	Returns the subtraction of this rational number with another.
+multiply(secondRational: Rational): Rational	Returns the multiplication of this rational number with another.
+divide(secondRational: Rational): Rational	Returns the division of this rational number with another.
+toString(): String	Returns a string in the form “numerator/denominator.” Returns the numerator if denominator is 1.
-gcd(n: long, d: long): long	Returns the greatest common divisor of n and d.

FIGURE 13.8 The properties, constructors, and methods of the `Rational` class are illustrated in UML.

A rational number consists of a numerator and a denominator. There are many equivalent rational numbers—for example, `1/3 = 2/6 = 3/9 = 4/12`. The numerator and the denominator of `1/3` have no common divisor except `1`, so `1/3` is said to be in *lowest terms*.

To reduce a rational number to its lowest terms, you need to find the greatest common divisor (GCD) of the absolute values of its numerator and denominator, then divide both the numerator and denominator by this value. You can use the method for computing the GCD of two integers `n` and `d`, as suggested in Listing 5.9, GreatestCommonDivisor.java. The numerator and denominator in a `Rational` object are reduced to their lowest terms.

As usual, let us first write a test program to create two `Rational` objects and test its methods. Listing 13.12 is a test program.

LISTING 13.12 TestRationalClass.java

```java
public class TestRationalClass {
  /** Main method */
  public static void main(String[] args) {
    // Create and initialize two rational numbers r1 and r2
    Rational r1 = new Rational(4, 2);                    create a Rational
    Rational r2 = new Rational(2, 3);                    create a Rational

    // Display results
```

add

```
 9       System.out.println(r1 + " + " + r2 + " = " + r1.add(r2));
10       System.out.println(r1 + " - " + r2 + " = " + r1.subtract(r2));
11       System.out.println(r1 + " * " + r2 + " = " + r1.multiply(r2));
12       System.out.println(r1 + " / " + r2 + " = " + r1.divide(r2));
13       System.out.println(r2 + " is " + r2.doubleValue());
14     }
15   }
```

```
2 + 2/3 = 8/3
2 - 2/3 = 4/3
2 * 2/3 = 4/3
2 / 2/3 = 3
2/3 is 0.6666666666666666
```

The **main** method creates two rational numbers, **r1** and **r2** (lines 5–6), and displays the results of **r1 + r2**, **r1 - r2**, **r1 x r2**, and **r1 / r2** (lines 9–12). To perform **r1 + r2**, invoke **r1.add(r2)** to return a new **Rational** object. Similarly, invoke **r1.subtract(r2)** for **r1 - r2**, **r1.multiply(r2)** for **r1 x r2** , and **r1.divide(r2)** for **r1 / r2**.

The **doubleValue()** method displays the double value of **r2** (line 13). **The doubleValue()** method is defined in **java.lang.Number** and overridden in **Rational**.

Note that when a string is concatenated with an object using the plus sign (**+**), the object's string representation from the **toString()** method is used to concatenate with the string. So **r1 + " + " + r2 + " = " + r1.add(r2)** is equivalent to **r1.toString() + " + " + r2.toString() + " = " + r1.add(r2).toString()**.

The **Rational** class is implemented in Listing 13.13.

LISTING 13.13 Rational.java

```
public class Rational extends Number implements Comparable<Rational> {
  // Data fields for numerator and denominator
  private long numerator = 0;
  private long denominator = 1;

  /** Construct a rational with default properties */
  public Rational() {
    this(0, 1);
  }

  /** Construct a rational with specified numerator and denominator */
  public Rational(long numerator, long denominator) {
    long gcd = gcd(numerator, denominator);
    this.numerator = ((denominator > 0) ? 1 : -1) * numerator / gcd;
    this.denominator = Math.abs(denominator) / gcd;
  }

  /** Find GCD of two numbers */
  private static long gcd(long n, long d) {
    long n1 = Math.abs(n);
    long n2 = Math.abs(d);
    int gcd = 1;

    for (int k = 1; k <= n1 && k <= n2; k++) {
      if (n1 % k == 0 && n2 % k == 0)
        gcd = k;
    }

    return gcd;
  }

  /** Return numerator */
  public long getNumerator() {
    return numerator;
  }

  /** Return denominator */
  public long getDenominator() {
    return denominator;
  }

  /** Add a rational number to this rational */
```

$\frac{a}{b} + \frac{c}{d} = \frac{ad + bc}{bd}$

```
  public Rational add(Rational secondRational) {
    long n = numerator * secondRational.getDenominator() +
      denominator * secondRational.getNumerator();
    long d = denominator * secondRational.getDenominator();
    return new Rational(n, d);
  }

  /** Subtract a rational number from this rational */
```

$\frac{a}{b} - \frac{c}{d} = \frac{ad - bc}{bd}$

```
  public Rational subtract(Rational secondRational) {
    long n = numerator * secondRational.getDenominator()
      - denominator * secondRational.getNumerator();
    long d = denominator * secondRational.getDenominator();
    return new Rational(n, d);
  }

  /** Multiply a rational number by this rational */
```

$\frac{a}{b} \times \frac{c}{d} = \frac{ac}{bd}$

```
  public Rational multiply(Rational secondRational) {
    long n = numerator * secondRational.getNumerator();
    long d = denominator * secondRational.getDenominator();
    return new Rational(n, d);
  }

  /** Divide a rational number by this rational */
```

$\frac{a}{b} \div \frac{c}{d} = \frac{ad}{bc}$

```
  public Rational divide(Rational secondRational) {
    long n = numerator * secondRational.getDenominator();
    long d = denominator * secondRational.numerator;
    return new Rational(n, d);
  }

  @Override
  public String toString() {
    if (denominator == 1)
      return numerator + "";
    else
      return numerator + "/" + denominator;
  }

  @Override // Override the equals method in the Object class
  public boolean equals(Object other) {
    if ((this.subtract((Rational)(other))).getNumerator() == 0)
      return true;
    else
      return false;
  }

  @Override // Implement the abstract intValue method in Number
  public int intValue() {
```

```
 90       return (int)doubleValue();
 91     }
 92 
 93     @Override // Implement the abstract floatValue method in Number
 94     public float floatValue() {
 95       return (float)doubleValue();
 96     }
 97 
 98     @Override // Implement the doubleValue method in Number
 99     public double doubleValue() {
100       return numerator * 1.0 / denominator;
101     }
102 
103     @Override // Implement the abstract longValue method in Number
104     public long longValue() {
105       return (long)doubleValue();
106     }
107 
108     @Override // Implement the compareTo method in Comparable
109     public int compareTo(Rational o) {
110       if (this.subtract(o).getNumerator() > 0)
111         return 1;
112       else if (this.subtract(o).getNumerator() < 0)
113         return -1;
114       else
115         return 0;
116     }
117   }
```

The rational number is encapsulated in a **Rational** object. Internally, a rational number is represented in its lowest terms (line 13), and the numerator determines its sign (line 14). The denominator is always positive (line 15).

The **gcd** method (lines 19–30 in the **Rational** class) is private; it is not intended for use by clients. The **gcd** method is only for internal use by the **Rational** class. The **gcd** method is also static, since it is not dependent on any particular **Rational** object.

The **abs(x)** method (lines 20–21 in the **Rational** class) is defined in the **Math** class and returns the absolute value of **x**.

Two **Rational** objects can interact with each other to perform add, subtract, multiply, and divide operations. These methods return a new **Rational** object (lines 43–70).

The methods **toString** and **equals** in the **Object** class are overridden in the **Rational** class (lines 72–86). The **toString()** method returns a string representation of a **Rational** object in the form **numerator/denominator**, or simply **numerator** if **denominator** is **1**. The **equals(Object other)** method returns true if this rational number is equal to the other rational number.

The abstract methods **intValue**, **longValue**, **floatValue**, and **doubleValue** in the **Number** class are implemented in the **Rational** class (lines 88–106). These methods return the **int**, **long**, **float**, and **double** value for this rational number.

The **compareTo(Rational other)** method in the **Comparable** interface is implemented in the **Rational** class (lines 108–116) to compare this rational number to the other rational number.

Tip

The getter methods for the properties **numerator** and **denominator** are provided in the **Rational** class, but the setter methods are not provided, so, once a **Rational** object is created, its contents cannot be changed. The **Rational** class is immutable. The **String** class and the wrapper classes for primitive type values are also immutable.

immutable

Tip

The numerator and denominator are represented using two variables. It is possible to use an array of two integers to represent the numerator and denominator (see Programming Exercise 13.14). The signatures of the public methods in the `Rational` class are not changed, although the internal representation of a rational number is changed. This is a good example to illustrate the idea that the data fields of a class should be kept private so as to encapsulate the implementation of the class from the use of the class.

encapsulation

The `Rational` class has serious limitations and can easily overflow. For example, the following code will display an incorrect result, because the denominator is too large.

overflow

```
public class Test {
  public static void main(String[] args) {
    Rational r1 = new Rational(1, 123456789);
    Rational r2 = new Rational(1, 123456789);
    Rational r3 = new Rational(1, 123456789);
    System.out.println("r1 * r2 * r3 is " +
      r1.multiply(r2.multiply(r3)));
  }
}
```

```
r1 * r2 * r3 is -1/2204193661661244627
```

To fix it, you can implement the `Rational` class using the `BigInteger` for numerator and denominator (see Programming Exercise 13.15).

13.30 Show the output of the following code?

```
Rational r1 = new Rational(-2, 6);
System.out.println(r1.getNumerator());
System.out.println(r1.getDenominator());
System.out.println(r1.intValue());
System.out.println(r1.doubleValue());
```

13.31 Why is the following code wrong?

```
Rational r1 = new Rational(-2, 6);
Object r2 = new Rational(1, 45);
System.out.println(r2.compareTo(r1));
```

13.32 Why is the following code wrong?

```
Object r1 = new Rational(-2, 6);
Rational r2 = new Rational(1, 45);
System.out.println(r2.compareTo(r1));
```

13.33 How do you simplify the code in lines 82–85 in Listing 13.13 Rational.java using one line of code without using the if statement?

13.34 Trace the program carefully and show the output of the following code.

```
Rational r1 = new Rational(1, 2);
Rational r2 = new Rational(1, -2);
System.out.println(r1.add(r2));
```

13.10 Class Design Guidelines

Class design guidelines are helpful for designing sound classes.

You have learned how to design classes from the preceding two examples and from many other examples in the preceding chapters. This section summarizes some of the guidelines.

13.10.1 Cohesion

coherent purpose

A class should describe a single entity, and all the class operations should logically fit together to support a coherent purpose. You can use a class for students, for example, but you should not combine students and staff in the same class, because students and staff are different entities.

separate responsibilities

A single entity with many responsibilities can be broken into several classes to separate the responsibilities. The classes `String`, `StringBuilder`, and `StringBuffer` all deal with strings, for example, but have different responsibilities. The `String` class deals with immutable strings, the `StringBuilder` class is for creating mutable strings, and the `StringBuffer` class is similar to `StringBuilder` except that `StringBuffer` contains synchronized methods for updating strings.

13.10.2 Consistency

naming conventions

Follow standard Java programming style and naming conventions. Choose informative names for classes, data fields, and methods. A popular style is to place the data declaration before the constructor and place constructors before methods.

naming consistency

Make the names consistent. It is not a good practice to choose different names for similar operations. For example, the `length()` method returns the size of a `String`, a `StringBuilder`, and a `StringBuffer`. It would be inconsistent if different names were used for this method in these classes.

no-arg constructor

In general, you should consistently provide a public no-arg constructor for constructing a default instance. If a class does not support a no-arg constructor, document the reason. If no constructors are defined explicitly, a public default no-arg constructor with an empty body is assumed.

If you want to prevent users from creating an object for a class, you can declare a private constructor in the class, as is the case for the `Math` class.

13.10.3 Encapsulation

encapsulate data fields

A class should use the `private` modifier to hide its data from direct access by clients. This makes the class easy to maintain.

Provide a getter method only if you want the data field to be readable, and provide a setter method only if you want the data field to be updateable. For example, the `Rational` class provides a getter method for `numerator` and `denominator`, but no setter method, because a `Rational` object is immutable.

13.10.4 Clarity

Cohesion, consistency, and encapsulation are good guidelines for achieving design clarity. Additionally, a class should have a clear contract that is easy to explain and easy to understand.

easy to explain

Users can incorporate classes in many different combinations, orders, and environments. Therefore, you should design a class that imposes no restrictions on how or when the user can use it, design the properties in a way that lets the user set them in any order and with any combination of values, and design methods that function independently of their order of occurrence. For example, the `Loan` class contains the properties `loanAmount`, `numberOfYears`, and `annualInterestRate`. The values of these properties can be set in any order.

independent methods

intuitive meaning

Methods should be defined intuitively without causing confusion. For example, the `substring(int beginIndex, int endIndex)` method in the `String` class is somewhat confusing. The method returns a substring from `beginIndex` to `endIndex – 1`, rather than to `endIndex`. It would be more intuitive to return a substring from `beginIndex` to `endIndex`.

independent properties

You should not declare a data field that can be derived from other data fields. For example, the following `Person` class has two data fields: `birthDate` and `age`. Since `age` can be derived from `birthDate`, `age` should not be declared as a data field.

```
public class Person {
  private java.util.Date birthDate;
```

```
    private int age;

    ...
  }
```

13.10.5 Completeness

Classes are designed for use by many different customers. In order to be useful in a wide range of applications, a class should provide a variety of ways for customization through properties and methods. For example, the `String` class contains more than 40 methods that are useful for a variety of applications.

13.10.6 Instance vs. Static

A variable or method that is dependent on a specific instance of the class must be an instance variable or method. A variable that is shared by all the instances of a class should be declared static. For example, the variable `numberOfObjects` in `CircleWithPrivateDataFields` in Listing 9.8 is shared by all the objects of the `CircleWithPrivateDataFields` class and therefore is declared static. A method that is not dependent on a specific instance should be defined as a static method. For instance, the `getNumberOfObjects()` method in `CircleWithPrivateDataFields` is not tied to any specific instance and therefore is defined as a static method.

Always reference static variables and methods from a class name (rather than a reference variable) to improve readability and avoid errors.

Do not pass a parameter from a constructor to initialize a static data field. It is better to use a setter method to change the static data field. Thus, the following class in (a) is better replaced by (b).

```
public class SomeThing {
  private int t1;
  private static int t2;

  public SomeThing(int t1, int t2) {
    ...
  }
}
```

(a)

```
public class SomeThing {
  private int t1;
  private static int t2;

  public SomeThing(int t1) {
    ...
  }

  public static void setT2(int t2) {
    SomeThing.t2 = t2;
  }
}
```

(b)

Instance and static are integral parts of object-oriented programming. A data field or method is either instance or static. Do not mistakenly overlook static data fields or methods. It is a common design error to define an instance method that should have been static. For example, the `factorial(int n)` method for computing the factorial of `n` should be defined static, because it is independent of any specific instance.

common design error

A constructor is always instance, because it is used to create a specific instance. A static variable or method can be invoked from an instance method, but an instance variable or method cannot be invoked from a static method.

13.10.7 Inheritance vs. Aggregation

The difference between inheritance and aggregation is the difference between an is-a and a has-a relationship. For example, an apple is a fruit; thus, you would use inheritance to model the relationship between the classes `Apple` and `Fruit`. A person has a name; thus, you would use aggregation to model the relationship between the classes `Person` and `Name`.

13.10.8 Interfaces vs. Abstract Classes

Both interfaces and abstract classes can be used to specify common behavior for objects. How do you decide whether to use an interface or a class? In general, a strong is-a relationship that clearly describes a parent–child relationship should be modeled using classes. For example, since an orange is a fruit, their relationship should be modeled using class inheritance. A weak is-a relationship, also known as an is-kind-of relationship, indicates that an object possesses a certain property. A weak is-a relationship can be modeled using interfaces. For example, all strings are comparable, so the **`String`** class implements the **`Comparable`** interface. A circle or a rectangle is a geometric object, so **`Circle`** can be designed as a subclass of **`GeometricObject`**. Circles are different and comparable based on their radii, so **`Circle`** can implement the **`Comparable`** interface.

Interfaces are more flexible than abstract classes, because a subclass can extend only one superclass but can implement any number of interfaces. However, interfaces cannot contain concrete methods. The virtues of interfaces and abstract classes can be combined by creating an interface with an abstract class that implements it. Then you can use the interface or the abstract class, whichever is convenient. We will give examples of this type of design in Chapter 20, Lists, Stacks, Queues, and Priority Queues.

Check Point

13.35 Describe class design guidelines.

Key Terms

abstract class	496
abstract method	496
deep copy	516
interface	496
marker interface	513
shallow copy	515
subinterface	518

Chapter Summary

1. *Abstract classes* are like regular classes with data and methods, but you cannot create instances of abstract classes using the **`new`** operator.

2. An *abstract method* cannot be contained in a nonabstract class. If a subclass of an abstract superclass does not implement all the inherited abstract methods of the superclass, the subclass must be defined as abstract.

3. A class that contains abstract methods must be abstract. However, it is possible to define an abstract class that doesn't contain any abstract methods.

4. A subclass can be abstract even if its superclass is concrete.

5. An *interface* is a class-like construct that contains only constants and abstract methods. In many ways, an interface is similar to an abstract class, but an abstract class can contain constants and abstract methods as well as variables and concrete methods.

6. An interface is treated like a special class in Java. Each interface is compiled into a separate bytecode file, just like a regular class.

7. The **`java.lang.Comparable`** interface defines the **`compareTo`** method. Many classes in the Java library implement **`Comparable`**.