Chapter 16

Using Inheritance and Polymorphism

In this chapter we make use of inheritance and polymorphism to build a useful data structure.

16.1 Abstract Classes

`Circle1a` (16.1) is a variation of `Circle1` (7.1) with the `circumference()` method renamed `perimeter()`.

```
public class Circle1a {
    private final double PI = 3.14159;
    private double radius;
    public Circle1a(double r) {
        radius = r;
    }
    public double perimeter() {
        return 2 * PI * radius;
    }
    public double area() {
        return PI * radius * radius;
    }
}
```

Listing 16.1: `Circle1a`—a slightly modified `Circle1`

Consider a new class—`Rectangle1a` (16.2). (The "`1a`" in its name simply implies that it is somehow associated with the `Circle1a` class.)

```
public class Rectangle1a {
    private double width;
    private double height;
    public Rectangle1a(double w, double h) {
```



```
        width = w;
        height = h;
    }
    public double area() {
        return width * height;
    }
    public double perimeter() {
        return 2*width + 2*height;
    }
}
```

Listing 16.2: `Rectangle1a`—a stateful rectangle

Objects of these classes represent circles and rectangles—simple two-dimensional geometric shapes. We say they are *kinds of* shapes; that is, a circle is a *kind of* shape, and a rectangle is another *kind of* shape. As such, these specific kinds of shapes exhibit some common characteristics; for example, they both have areas and perimeters. We can *classify* these specific circle and rectangle shapes under the general category of *shapes*.

Suppose we want to write a method that would accept any kind of shape object and use the methods common to all shape objects to compute some useful result; for example, the perimeter-to-area ratio of an object, as in `PerimeterToAreaRatio` (16.3).

```
public class PerimeterToAreaRatio {
    public static double perimeterToAreaRatio(Shape s) {
        return s.perimeter()/s.area();
    }
}
```

Listing 16.3: `PerimeterToAreaRatio`—computes the perimeter-to-area ratio of a geometric shape

Observe that if we replace `Shape` in the parameter list of `perimeterToAreaRatio()` with `Circle1a`, it will work for `Circle1a` objects. Similarly, if we replace `Shape` with `Rectangle1a`, it will work for `Rectangle1a` objects. We do not want to write two different `perimeterToAreaRatio()` methods, one for each shape type. Instead, we really want only one method that works on both shape types, as shown here in the `PerimeterToAreaRatio` class. Inheritance provides the way the make this happen.

In OOP, we use *class hierarchies* formed by inheritance relationships to classify kinds of objects. A Java class represents a kind of an object. When two classes share properties and are related to each other conceptually, we often can create a a new class exhibiting those common properties. We then modify the two original classes to make them subclasses of the new class. In our example, circles have areas and perimeters, and rectangles have areas and perimeters. Both are kinds of shapes, so we can make a new class named `Shape` and make `Circle1a` and `Rectangle1a` subclasses of `Shape`.

How do we capture the notion of a general, nonspecific shape in a Java class? Here are our requirements:

- We would name the class `Shape`.

- Any object that is a kind of `Shape` should be able to compute its area and perimeter through methods named `area()` and `perimeter()`. (`Circle1a` and `Rectangle1a` object both qualify.)
- We cannot write actual code for the `area()` and `perimeter()` methods in our generic `Shape` class because we do not have a specific shape. No universal formula exists to compute the area of any shape because shapes are so different.
- Clients should be unable to create instances of our `Shape` class. We can draw a circle with a particular radius or a rectangle with a given width and height, but how do we draw a generic shape? The notion of a *pure* shape is too abstract to draw. Likewise, our `Shape` class captures an abstract concept that cannot be materialized into a real object.

Java provides a way to define such an abstract class, as shown in `Shape` (16.4).

```
public abstract class Shape {
    public abstract double area();
    public abstract double perimeter();
}
```

Listing 16.4: `Shape`—a generic shape

In `Shape` (16.4):

- The class is declared `abstract`. Such a class is called an *abstract class*. We are unable to create instances of an abstract class, just as we really cannot have a plain shape object that is not some kind of specific shape.
- An abstract class may have zero or more methods that are declared `abstact`. Abstract methods have no bodies; a semicolon appears where the body of a non-abstract method would normally go. We are *declaring* the method but not *defining* it. Since we have no concrete information about a generic shape we cannot actually compute area and perimeter, so both of these methods are declared `abstract`.
- While not shown here, an abstract class may contain concrete (that is, non-abstract) methods as well. An abstract class can have non-`abstract` methods, but a non-`abstract` class may not contain any `abstract` methods.

A non-abstract class is called a *concrete class*. All classes are either abstract or concrete. All the classes we considered before this chapter have been concrete classes. A non-`abstract` method is called a concrete method. A concrete class may not contain abstract methods, but an abstract class may contain both abstract methods and concrete methods.

Given our `Shape` class we can now provide the concrete subclasses for the specfic shapes in `Circle` (16.5) and `Rectangle` (16.6).

```
public class Circle extends Shape {
    private final double PI = 3.14159;
    private double radius;
    public Circle(double r) {
        radius = r;
    }
```



```
    public double perimeter() {
        return 2 * PI * radius;
    }
    public double area() {
        return PI * radius * radius;
    }
}
```

Listing 16.5: `Circle`—a circle subclass

```
public class Rectangle extends Shape {
    private double width;
    private double height;
    public Rectangle(double w, double h) {
        width = w;
        height = h;
    }
    public double area() {
        return width * height;
    }
    public double perimeter() {
        return 2* width + 2 * height;
    }
}
```

Listing 16.6: `Rectangle`—a rectangle subclass

Now `PerimeterToAreaRatio` (16.3) works as is on any `Shape` subclass. Polymorphism enables the perimeterToAreaRatio() to execute the proper `area()` and `perimeter()` code for the object at hand. Figure 16.1 shows the UML diagram for our shapes class hierarchy. Abstract class names are shown in italics in the UML class diagrams.

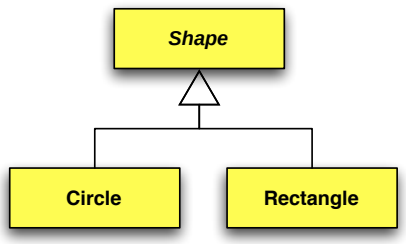


Figure 16.1: Class hierarchy of shape classes. It is common practice to omit the superclass of `Shape`; that is, the `java.lang.Object` class is not shown here.

Suppose we must develop an inventory program for a produce market. One of the market's specialties is fresh fruit, including bananas and several varieties of apples and grapes. For example, we might have a class for golden

delicious apples and another for granny smith apples. We note that both varieties have some common properties (after all, they are both kinds of apples). It makes sense to create a common superclass, `Apple`, and derive the `GoldenDelicious` and `GrannySmith` classes from `Apple`, specializing the subclasses as required. Classes for red and white grapes could have `Grape` as a common superclass. Further, all fruit have some common properties, like color (red, yellow, etc.), taste (sweet, tangy, etc.), and size (volume or mass). Given this scenario we can create a hierarchy of classes as illustrated by the UML diagram in Figure 16.2. Ordinarily, we use classes as a blueprint

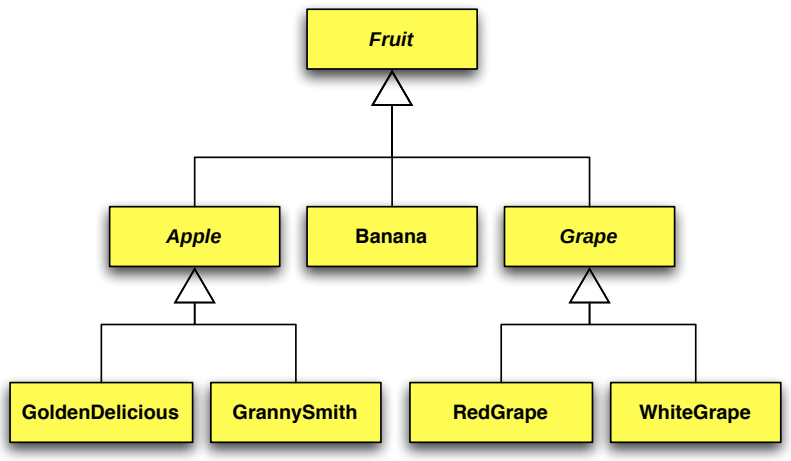


Figure 16.2: Class hierarchy of fruit classes.

for creating objects. We note that while golden delicious apples and granny smith apples would have a place in the inventory database, generic "apples" would not.

To recap, when two or more classes have common characteristics, and the classes conceptually represent specific examples of some more general type, we can use inheritance to factor out their common properties. We do so as follows:

- Make a new superclass that contains the common characteristics.
- Declare the class `abstract` if it represents an abstract concept and actual objects of this class do not make sense because there is not enough specific information to implement all of its required functionality.
- Modify the existing specific classes to be subclasses of the new superclass.

The new superclass is meant to distill the common characteristics of its subclasses. It represents the abstract notion of what it means to be instances of any of its subclasses.

16.2 A List Data Structure

Armed with our knowledge of inheritance, polymorphism, Java's wrapper classes (§ 13.4), and abstract classes, we can build a versatile list data structure. First, we need to think about the nature of lists:

- A list holds a collection of items in a *linear sequence*. Every nonempty linear sequence has the following properties:
  - there exists a unique first item in the list
  - there exists a unique last item in the list

  - every item except the first item has a unique predecessor
  - every item except the last item has a unique successor

- An empty list contains nothing. One empty list is indistinguishable from any other empty list. It follows that there should be exactly one empty list object, because making more than one does not provide any advantages.
- We can view any nonempty list as the first item followed by a list (the rest of the list). A nonempty list has at least one item. In a list containing only one item, the rest of the list refers to the empty list.
- It is easy to determine the number of items in a list:
  - If the list is empty, the number of items it contains is zero.
  - If the list is nonempty, the number of items it contains is one (for its first item) plus the number of items in the rest of the list.

  As we shall see, this recursive description is readily translated into a recursive method.
- It is easy to add an item to the end of a list:
  - If the list is empty, we just make a new nonempty list whose first item is the item we wish to add. The rest of this new list is the empty list.
  - If the list is nonempty, we simply add the new item to the rest of this list.

  This recursive algorithm also is easily translated into Java code.

As you can see, we have two distinct kinds of lists: empty lists and nonempty lists. We have to be able to treat both empty and nonempty lists as just *lists* even though empty lists and nonempty lists are functionally different kinds of objects. We need to distill the properties common to all kinds of lists into an abstract list class. From this abstract list class we will derive the concrete subclasses for empty and nonempty list objects. Figure 16.3 shows the resulting class hierarchy.

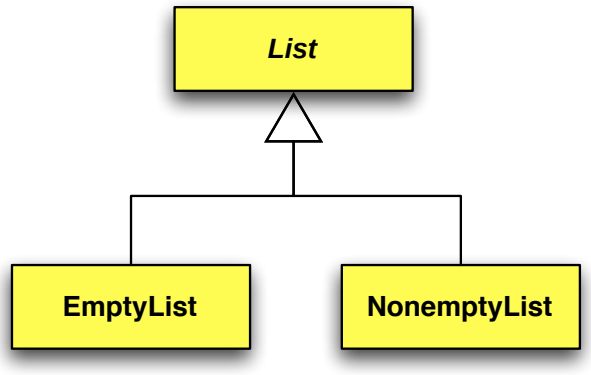


Figure 16.3: Class hierarchy of list classes.

`List` (16.7) provides good starting point:

```
public abstract class List {
    public abstract int length();
    public abstract List append(Object newElement);
    public String toString() {
```



```
        return "[" + toStringHelper() + "]";
    }
    protected  abstract String toStringHelper();
}
```

Listing 16.7: `List`—Abstract superclass for list objects

As we can see in `List` (16.7):

- Any list object can determine its length; that is, the number of elements it holds.

  ```
  public abstract int length();
  ```

  We cannot specify how this method should work since empty and nonempty lists will do this differently; therefore, this method is abstract.

- New items can be appended to any list object.

  ```
  public abstract List append(Object newElement);
  ```

  Again, we do not have enough detail in a generic list to indicate exactly how this is to be done, so `append()` is declared abstract. The parameter type of `append()` is `Object`. Since all classes are subclasses of `Object` (§ 14.1), either directly or indirectly, this means any reference type can be added to our list. Since all the primitive types have wrapper classes (§ 13.4), any primitive type as well can be added to our list. This means anything can be added to a list, even another list!

  The return type is `List`, but when a subclass overrides the `append()` method it will actually return a reference to an instance of a subclass of `List`. Because of the *is a* relationship, this is legal. For all we know now, the `append()` method returns a reference to some kind of list object.

- Every list object can be rendered as a string in the same way: The first character is `[` and the last character is `]`. The characters in between are determined by another method, `toStringHelper()`. Since actual code can be written for the `toString()` method, this method is concrete, not abstract.

- The `toStringHelper()` method is abstract, since for a generic list object we cannot know how to access its contents, if indeed it has any contents. It uses a new access privilege—`protected`. A `protected` member is accessible to code in subclasses and classes within the same package, but inaccessible to all other classes. This is exactly the level of protection we need here. `toStringHelper()` is meant to be an internal helper method; it is not meant to be used by clients. Making it `private`, however, would make it inaccessible to subclasses, meaning that subclasses could not override it. Since it is declared abstract, concrete subclasses *must* override it. The `protected` specifier essentially means `public` to subclasses and classes within the same package and `private` to all other classes.

Since `List` is abstract, we cannot create actual `List` objects. `List` serves as the superclass for two concrete subclasses that we will use to build real lists. The first is `EmptyList` (16.8):


```
public class EmptyList extends List {
    //  This constant is used when an empty list is needed
    public static final List EMPTY = new EmptyList();

    private EmptyList() {} //  Cannot create an instance of EmptyList

    public int length() {
        return 0;
    }
    public List append(Object newElement) {
        return new NonemptyList(newElement, EMPTY);
    }
    protected String toStringHelper() {
        return " ";
    }
}
```

Listing 16.8: `EmptyList`—Class for empty list objects

Despite its small size, `EmptyList` (16.8) is full of interesting features:

- `EmptyList` is a subclass of `List`,

  ```
  public class EmptyList extends List {
  ```

  but it is concrete; therefore, it may not contain any abstract methods. As we determined above, however, it should be trivial to add the needed functionality to empty lists.

- A class constant consisting of an `EmptyList` instance

  ```
  public static final List EMPTY = new EmptyList();
  ```

  is made available to clients for general use. As indicated in the next item, any reference to an empty list *must* use this constant.

- The only constructor is private.

  ```
  private EmptyList() {} //  Cannot create an instance of EmptyList
  ```

  As the comment says, this means clients are not allowed to create `EmptyList` objects directly using the `new` operator. For example, the statement

  ```
  EmptyList e = new EmptyList();      //  Compiler error!
  ```

  appearing anywhere outside of this class will result in a compiler error. This fact coupled with the `EMPTY` `EmptyList` constant means that exactly one `EmptyList` object will ever exist when this class is used. We say that `EMPTY` is a *singleton* empty list object.

- Empty lists trivially have no elements:

```
public int length() {
    return 0;
}
```

  so the length of an empty list is always zero.

- Appending a new item to an empty list results in a new nonempty list:

```
public List append(Object newElement) {
    return new NonemptyList(newElement, EMPTY);
}
```

  We will see the `NonemptyList` class next. Its constructor takes two arguments:

  – The first argument is the first item in the list.
  – The second argument is the rest of this new nonempty list.

  Observe that the net effect is to make a list containing only one element—exactly what we need when appending to an empty list.

- Converting the contents of the empty list to a string is also trivial.

```
protected String toStringHelper() {
    return " ";
}
```

  The `toStringHelper()` method simply returns a space—there are no elements to show.

- The `toString()` method is inherited from `List`. It ensures the contents of the resulting string are bracketed within `[ ]`. This superclass `toString()` method calls `toStringHelper()` polymorphically, so the correct `toStringHelper()` is called for the exact type of the list object.

Even though `EmptyList` is a concrete class, we cannot use it until we implement `NonemptyList` (16.9):

```
public class NonemptyList extends List {
    private Object first;
    private List rest;

    public NonemptyList(Object f, List r) {
        first = f;
        rest = r;
    }

    public int length() {
        return 1 + rest.length();
    }
```



```
    public List append(Object newElement) {
        return new NonemptyList(first, rest.append(newElement));
    }

    protected String toStringHelper() {
        return " " + first + rest.toStringHelper();
    }
}
```

Listing 16.9: `NonemptyList`—Class for nonempty list objects

In `NonemptyList` (16.9):

- Two private fields:

  ```
  private Object first;
  private List rest;
  ```

  capture our original definition of what constitutes a nonempty list:

  – Every nonempty list has a first item (`first`), and
  – every nonempty list has the rest of the list (`rest`) that follows the first item.

- The type of `first` is `Object`. The practical result is any type of data can be assigned to the `first` instance variable.

- The type of `rest` is `List`. This means references to both `EmptyList` objects and `NonemptyList` objects can be assigned to the `rest` instance variable. A list that contains only one item would assign the item to `first` and then assign `rest` to the empty list.

- The constructor initializes the instance variables:

  ```
  public NonemptyList(Object f, List r) {
      . . .
  ```

- The `length()` method

  ```
  public int length() {
      return 1 + rest.length();
  }
  ```

  works exactly as we originally specified. The length of a nonempty list is one (for its first item) plus the length of the rest of the list. Note the recursive nature of this method. It is up to the remainder of the list (referenced by `rest`) to compute its own length. Empty lists will report zero, and nonempty lists call this same method polymorphically but with a different object.

- The `append()` method


```
public List append(Object newElement) {
    return new NonemptyList(first, rest.append(newElement));
}
```

simply creates a new list object. We know for sure the type of list to create is a `NonemptyList` since we are appending an item onto the current (nonempty) list. The first item in the new list will be the same as the first item in this list. The rest of the new list is the result of appending the new item to the end of the current rest of the list. The recursive nature of the method call leads eventually to an attempt to append the new item to the empty list. The recursion stops there (the `append()` method in `EmptyList` is definitely nonrecursive), and a new nonempty list containing the new item is returned.

- The `toStringHelper()` method

```
protected String toStringHelper() {
    return " " + first + rest.toStringHelper();
}
```

is another recursive procedure. We append the first item and then defer the rest of the task to the `rest` object.

- As with `EmptyList`, the `toString()` method is inherited from `List`. When this superclass `toString()` method is called on behalf of a `NonemptyList` object, `toString()` calls `NonemptyList`'s `toStringHelper()` polymorphically.

We now have everything in place to experiment with our new list data structure:

Interactions

```
Welcome to DrJava.  Working directory is /Users/rick/java
> e = new EmptyList();  //  Attempt to create an empty list
IllegalAccessException: Class
koala.dynamicjava.interpreter.context.GlobalContext can not access a
member of class EmptyList with modifiers "private"
  at sun.reflect.Reflection.ensureMemberAccess(Reflection.java:65)
  at java.lang.reflect.Constructor.newInstance(Constructor.java:486)
> e = EmptyList.EMPTY;  //  Do it the intended way
> e
[ ]
> list1 = e.append("Fred");
> list1
[ Fred ]
> list2 = list1.append("Wilma");
> list2
[ Fred Wilma ]
> list3 = list2.append(19.37);
> list3
[ Fred Wilma 19.37 ]
> list4 = list3.append(15);
> list4
[ Fred Wilma 19.37 15 ]
> list5 = list4.append("Barney");
> list5
```



```
[ Fred Wilma 19.37 15 Barney ]
> list5.length()
5
```

Figure 16.4 illustrates the data structure referenced by `list5` as created by this sequence of interactions. If the

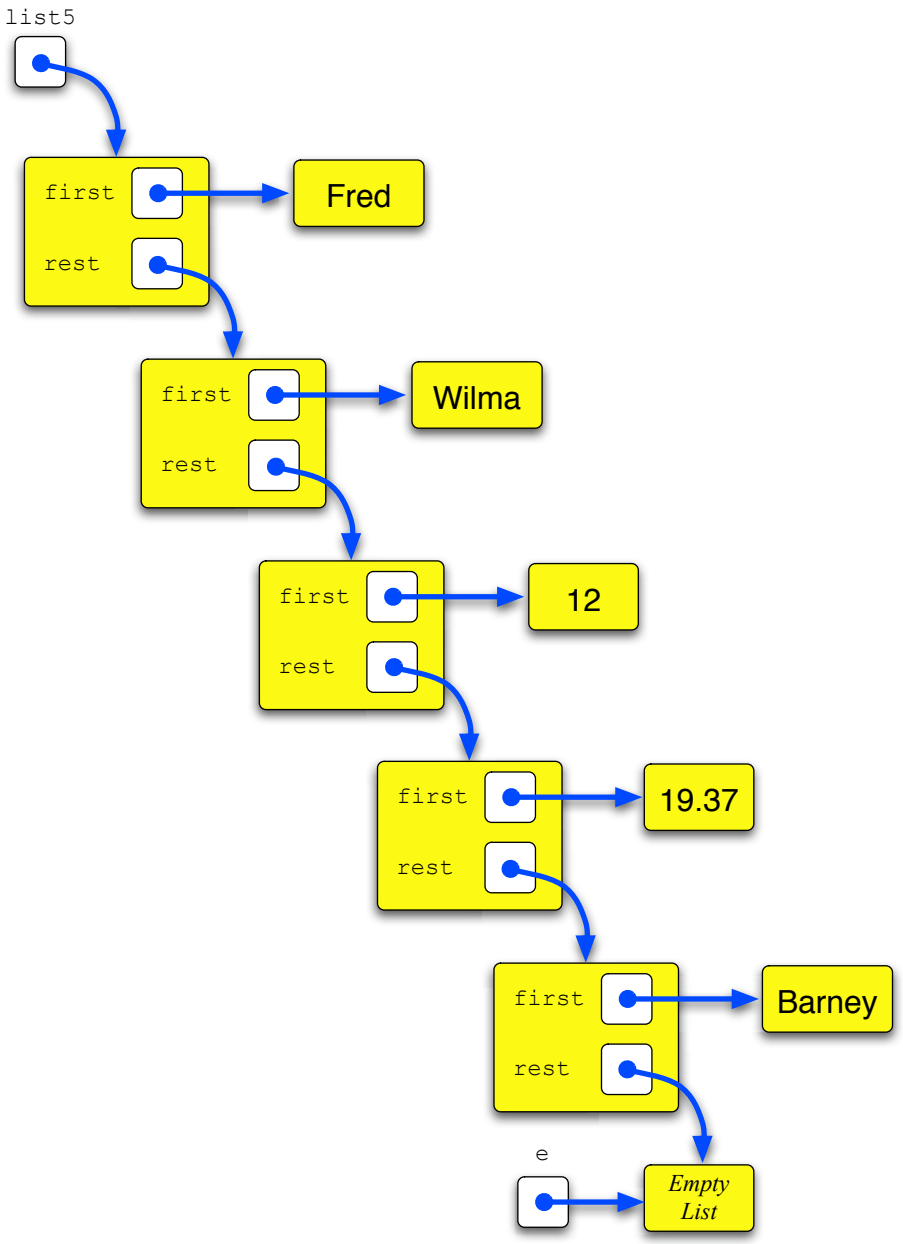
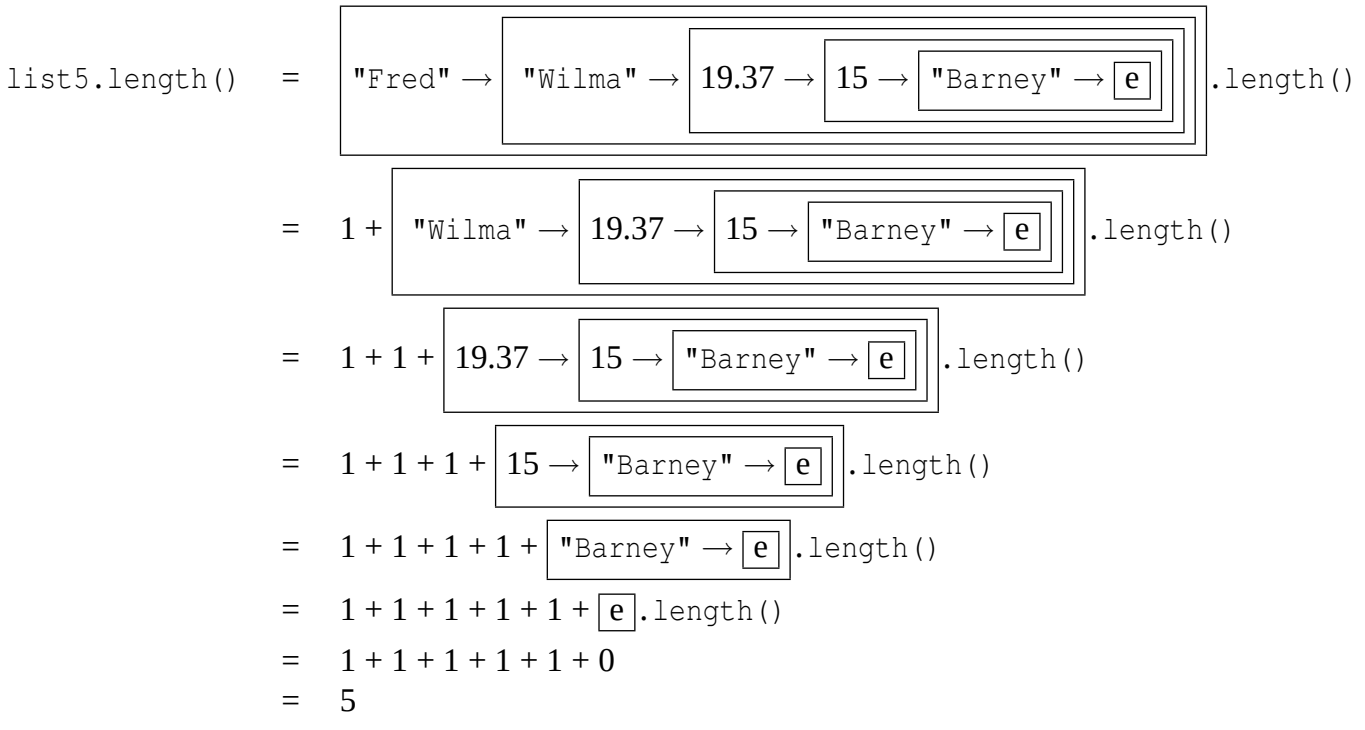


Figure 16.4: Data structure created by the interactive sequence

structure of list `list5` is represented by the following:

`list5` = `"Fred"` → `"Wilma"` → 19.37 → 15 → `"Barney"` → e

then the activity performed by the call `list5.length()` is



The compiler automatically creates the appropriate wrapper objects for the primitive types 19.37 and 15.

Like Java's `String` objects, our list objects are immutable. Clients cannot modify the contents of a list. Our `append()` method does not modify an existing list; it creates a new list with the new item added on the end. The original list is unaffected by the action. What if we wish to modify a list? We can simply reassign the list reference, as is:

```
list5 = list5.append(2);
```

In this case the original list of `list5` is replaced by the new list created by the `append()` method call.

As an interesting side note, since our lists can hold any kinds of objects, we can easily have lists of lists:

Interactions

```
Welcome to DrJava.  Working directory is /Users/rick/java
> list = EmptyList.EMPTY;
> list
[ ]
> list = list.append(19.37);
> list
[ 19.37 ]
> list = list.append("Fred");
> list = list.append("Wilma");
> list
[ 19.37 Fred Wilma ]
> list.length()
3
> list = list.append(list);
> list
[ 19.37 Fred Wilma [ 19.37 Fred Wilma ] ]
> list.length()
4
```


The length of the whole list at the end is four since the last element (itself a list) is a single object (a `NonemptyList` object).

`ListTest` (16.10) provides some lightweight testing for our list data structure.

```
import junit.framework.TestCase;

public class ListTest extends TestCase {

    public void testAppendMethod() {
        List list = EmptyList.EMPTY;
        assertEquals("[ ]", list.toString());
        assertEquals(0, list.length());
        list = list.append(22);
        //System.out.println(list);
        assertEquals("[ 22 ]", list.toString());
        assertEquals(1, list.length());
        list = list.append("Fred");
        assertEquals("[ 22 Fred ]", list.toString());
        assertEquals(2, list.length());
        list = list.append(2.2);
        assertEquals("[ 22 Fred 2.2 ]", list.toString());
        assertEquals(3, list.length());
        list = list.append("Wilma");
        assertEquals("[ 22 Fred 2.2 Wilma ]", list.toString());
        assertEquals(4, list.length());
    }
}
```

Listing 16.10: `ListTest`—JUnit test file

To conclude, it is important to note that the immutable list implementation presented here is simple and elegant but not very efficient. A nonrecursive, mutable version presented in § 18.4 is more efficient. We will consider this more efficient implementation after we cover iteration in Chapter 17.

16.3 Interfaces

Java provides a construct that is similar to an abstract class with methods that are exclusively `public` and `abstract`. An `interface` specifies a collection of methods that any class that is to comply with that interface must implement. Since `Shape` (16.4) is an abstract class containing no instances variables and no concrete methods, it can be expressed as an interface, as shown in `IShape` (16.11).

```
public interface IShape {
    double area();
    double perimeter();
}
```


Listing 16.11: `IShape`—an interface for shape objects

From the `IShape` interface we can now specify that particular classes comply with the interface using the `implements` keyword, as shown in `Ring` (16.12) and `Quadrilateral` (16.13).

```
public class Ring implements IShape {
    private final double PI = 3.14159;
    private double radius;
    public Ring(double r) {
        radius = r;
    }
    public double perimeter() {
        return 2 * PI * radius;
    }
    public double area() {
        return PI * radius * radius;
    }
}
```

Listing 16.12: `Ring`—a ring (circle) class implementing the shape interface

```
public class Quadrilateral implements IShape {
    private double width;
    private double height;
    public Quadrilateral(double w, double h) {
        width = w;
        height = h;
    }
    public double area() {
        return width * height;
    }
    public double perimeter() {
        return 2* width + 2 * height;
    }
}
```

Listing 16.13: `Quadrilateral`—a quadrilateral (rectangle) class implementing the shape interface

The `Ring` and `Quadrilateral` classes both implement the `IShape` interface. They must contain at least the methods defined in `IShape`, but implementing classes can add additional methods and add fields.

Methods defined in interfaces are implicitly `abstract` and `public`; thus, `area()` and `perimeter()` within `IShape` are `public abstract` methods. An interface is like an abstract class in that it is not possible to create instances of interfaces. Such a statement is illegal:


```
IShape shape = new IShape();  //  Illegal to create an instance
```

an interface cannot contain instance variables or general class variables but can define constants (`final static` fields).

An interface serves as a contract that classes must fulfill that claim to comply with that interface. A class declares that it implements an interface with the `implements` keyword followed by a list of interfaces with which it complies. Unlike subclassing, where a single class cannot have more than one superclass, a class may implement multiple interfaces. In fact, any programmer-defined class *will* definitely extend a class (`Object`, if nothing else) and also *may* implement one or more interfaces.

Like a class, an interface defines a type; an implementing class is a subtype of the interface, just like a subclass is a subtype of its superclass. A special relationship exists between an interface and a class that implements that interface. This relationship is a *can do* relationship because an interface expresses what *can be done* in terms of method signatures. The interface specifies *what* can be done but cannot express *how* it is to be done. The how can only be specified in a method body, but in an interface all methods must be abstract. In practice, however, the *can do* relationship behaves like the *is a* relationship; that is, an object that is a subtype of an interface can be used in any context that expects the interface type. `ShapeReport` (16.14) shows how this subtyping relationship works.

```
public class ShapeReport {
    public static void report(IShape shape) {
        System.out.println("Area = " + shape.area()
                           + ", perimeter = " + shape.perimeter());
    }
    public static void main(String[] args) {
        IShape rect = new Quadrilateral(10, 2.5),
               circ = new Ring(5.0);
        report(rect);
        report(circ);
    }
}
```

Listing 16.14: `ShapeReport`—Illustrates the *is a* relationship for interfaces

Notice two things in `ShapeReport`:

- The `report()` method in `ShapeReport` expects an `IShape` type and works equally well with `Quadrilateral` and `Ring` objects. This is because of the *can do* relationship between an interface and its implementing class.
- In `main()`, the declared type of both `rect` and `circ` is `IShape`. While a literal `IShape` object cannot be created, a `Quadrilateral` object can be assigned to an `IShape` reference. Likewise, a `Ring` object can be assigned to an `IShape` reference. Again, this is because of the `can do` relationship between the implementing classes and `IShape`.

The reason that the parameter passing and assignment works is that, just as a subclass reference can be assigned to a superclass reference, a reference to a subtype can be assigned to a supertype reference. In fact the subclass-superclass relationship is a special case of the subtype-supertype relationship: the superclass of a class is its supertype, and a subclass of a class is a subtype of that class.

16.4 Summary

- A Java class represents a kind of an object, and a common superclass is used to organize different kinds of objects with common characteristics into the same category.
- An abstract method has no body.
- Concrete subclasses must override inherited abstract methods.
- A concrete class may not contain any abstract methods.
- An abstract class contains zero or more abstract methods.
- An abstract class may contain concrete methods.
- In a UML diagram, the name of an abstract class is italicized, and the name of a concrete class is not italicized.

16.5 Exercises

1. What reserved word specifies a class to be abstract?
2. Can instances be made of an abstract class?
3. Can all the methods in an abstract class be concrete?
4. Can any methods in a concrete class be abstract?
5. In Figure 16.2, which classes are abstract and which are concrete?
6. Explain how the `append()` method in the `NonemptyList` class correctly adds new elements to the end of the list.
7. Add the following methods to the `List` class and each of its subclasses as necessary:
   (a) `public List prepend(Object newElement)` — inserts a new element onto the front of the list
   (b) `public List concat(List other)` — splits two lists together in a manner analogous to string concatenation.
   (c) `public boolean contains(Object seek)` — returns `true` if `seek` is found in the list; otherwise, returns `false`. The `equals()` should be used to check for equality.
   (d) `public boolean equals(List other)` — determines if two lists contain the same elements (using their `equals()` methods) in the same order.
   (e) `public Object get(int index)` — returns the item in position `index`. The first element in a nonempty list is at index zero. The method should return `null` if an invalid index is given:
      - Any index is invalid for an empty list.
      - In a nonempty list with n elements, a valid index is in the range $0 \leq$ `index` $< n$.
8. Use list object to record the states that a traffic light assumes. This will keep a log of all the states that a traffic light enters. Make a new traffic light type named `LoggedTrafficLight`, a subclass of `TextTrafficLight` (10.2). Every call to its `setState()` method should append the requested state to the end of the list. Add a method named `reviewLog()` that simply prints out, in order, the states assumed by the traffic light since its creation. You should use but **not** modify the code of `TrafficLightModel` (10.1) and `TextTrafficLight` (10.2).

