10.4 Abstract Classes and Methods

When we think of a class, we assume that programs will create objects of that type. Sometimes it's useful to declare classes—called **abstract classes**—for which you *never* intend to create objects. Because they're used only as superclasses in inheritance hierarchies, we refer to them as **abstract superclasses**. These classes cannot be used to instantiate objects, because, as we'll soon see, abstract classes are *incomplete*. Subclasses must declare the "missing pieces" to become "concrete" classes, from which you can instantiate objects. Otherwise, these subclasses, too, will be abstract. We demonstrate abstract classes in Section 10.5.

Purpose of Abstract Classes

An abstract class's purpose is to provide an appropriate superclass from which other classes can inherit and thus share a common design. In the `Shape` hierarchy of Fig. 9.3, for example, subclasses inherit the notion of what it means to be a `Shape`—perhaps common attributes such as `location`, `color` and `borderThickness`, and behaviors such as `draw`, `move`, `resize` and `changeColor`. Classes that can be used to instantiate objects are called **concrete classes**. Such classes provide implementations of *every* method they declare (some of the implementations can be inherited). For example, we could derive concrete classes `Circle`, `Square` and `Triangle` from abstract superclass `TwoDimensionalShape`. Similarly, we could derive concrete classes `Sphere`, `Cube` and `Tetrahedron` from abstract superclass `ThreeDimensionalShape`. Abstract superclasses are *too general* to create real objects—they specify only what is common among subclasses. We need to be more *specific* before we can create objects. For example, if you send the `draw` message to abstract class `TwoDimensionalShape`, the class knows that two-dimensional shapes should be *drawable*, but it does not know what *specific* shape to draw, so it cannot implement a real `draw` method. Concrete classes provide the specifics that make it reasonable to instantiate objects.

Not all hierarchies contain abstract classes. However, you'll often write client code that uses only abstract superclass types to reduce the client code's dependencies on a range of subclass types. For example, you can write a method with a parameter of an abstract superclass type. When called, such a method can receive an object of *any* concrete class that directly or indirectly extends the superclass specified as the parameter's type.

Abstract classes sometimes constitute several levels of a hierarchy. For example, the `Shape` hierarchy of Fig. 9.3 begins with abstract class `Shape`. On the next level of the hierarchy are *abstract* classes `TwoDimensionalShape` and

`ThreeDimensionalShape`. The next level of the hierarchy declares *concrete* classes for `TwoDimensionalShape`s (`Circle`, `Square` and `Triangle`) and for `ThreeDimensionalShape`s (`Sphere`, `Cube` and `Tetrahedron`).

Declaring an Abstract Class and Abstract Methods

You make a class abstract by declaring it with keyword `abstract`. An abstract class normally contains one or more **abstract methods**. An abstract method is an *instance method* with keyword `abstract` in its declaration, as in

```
public abstract void draw(); // abstract method
```

Abstract methods do *not* provide implementations. A class that contains *any* abstract methods must be explicitly declared `abstract` even if that class contains some concrete (nonabstract) methods. Each concrete subclass of an abstract superclass also must provide concrete implementations of each of the superclass's abstract methods. Constructors and `static` methods cannot be declared `abstract`. Constructors are *not* inherited, so an `abstract` constructor could never be implemented. Though non-`private` `static` methods are inherited, they cannot be overridden. Since `abstract` methods are meant to be overridden so that they can process objects based on their types, it would not make sense to declare a `static` method as `abstract`.

Software Engineering Observation 10.4

An `abstract` *class declares common attributes and behaviors (both* `abstract` *and concrete) of the classes in a class hierarchy. An* `abstract` *class typically contains one or more* `abstract` *methods that subclasses must override if they are to be concrete. The instance variables and concrete methods of an* `abstract` *class are subject to the normal rules of inheritance.*

Common Programming Error 10.1

Attempting to instantiate an object of an abstract class is a compilation error.

Common Programming Error 10.2

Classes must be declared `abstract` *if they declare* `abstract` *methods or if they inherit* `abstract` *methods and do not provide concrete implementations of them; otherwise, compilation errors occur.*

Using Abstract Classes to Declare Variables

Although we cannot instantiate objects of abstract superclasses, you'll soon see that we *can* use abstract superclasses to declare variables that can hold references to objects of *any* concrete class *derived from* those abstract superclasses. We'll use such variables to manipulate subclass objects *polymorphically*. You also can use abstract superclass names to invoke `static` methods declared in those abstract superclasses.

Consider another application of polymorphism. A drawing program needs to display many shapes, including types of new shapes that you'll *add* to the system *after* writing the drawing program. The drawing program might need to display shapes, such as `Circle`s, `Triangle`s, `Rectangle`s or others, that derive from abstract class `Shape`. The drawing program uses `Shape` variables to manage the objects that are displayed. To draw any object in this inheritance hierarchy, the drawing program uses a superclass `Shape` variable containing a reference to the subclass object to invoke the object's `draw` method. This method is declared `abstract` in superclass

`Shape`, so each concrete subclass *must* implement method `draw` in a manner specific to that shape—each object in the `Shape` inheritance hierarchy *knows how to draw itself*. The drawing program does not have to worry about the type of each object or whether the program has ever encountered objects of that type.

Layered Software Systems

Polymorphism is particularly effective for implementing so-called *layered software systems*. In operating systems, for example, each type of physical device could operate quite differently from the others. Even so, commands to read or write data from and to devices may have a certain uniformity. For each device, the operating system uses a piece of software called a *device driver* to control all communication between the system and the device. The write message sent to a device-driver object needs to be interpreted specifically in the context of that driver and how it manipulates devices of a specific type. However, the write call itself really is no different from the write to any other device in the system—place some number of bytes from memory onto that device. An object-oriented operating system might use an abstract superclass to provide an "interface" appropriate for all device drivers. Then, through inheritance from that abstract superclass, subclasses are formed that all behave similarly. The device-driver methods are declared as abstract methods in the abstract superclass. The implementations of these abstract methods are provided in the concrete subclasses that correspond to the specific types of device drivers. New devices are always being developed, often long after the operating system has been released. When you buy a new device, it comes with a device driver provided by the device vendor. The device is immediately operational after you connect it to your computer and install the driver. This is another elegant example of how polymorphism makes systems *extensible*.