



Chapter 10

Object-Oriented Programming: Polymorphism



OBJECTIVES

In this Chapter you'll learn:

- The concept of polymorphism.
- To use overridden methods to effect polymorphism.
- To distinguish between abstract and concrete classes.
- To declare abstract methods to create abstract classes.
- How polymorphism makes systems extensible and maintainable.
- To determine an object's type at execution time.
- To declare and implement interfaces.



10.1 Introduction

▶ Polymorphism

- Enables you to “program in the general” rather than “program in the specific.”
- Polymorphism enables you to write programs that process objects that share the same superclass **as if they’re all objects of the superclass**; this can simplify programming.



10.1 Introduction (Cont.)

- ▶ Example: Suppose we create a program that simulates the movement of several types of animals for a biological study. Classes **Fish**, **Frog** and **Bird** represent the three types of animals under investigation.
 - Each class extends superclass **Animal**, which contains a method **move** and maintains an animal's current **location** as *x*-*y* coordinates. Each subclass implements method **move**.
 - A program maintains an **Animal** array containing references to objects of the various **Animal** subclasses. To simulate the animals' movements, the program sends each object the same message once per second—namely, **move**.



10.1 Introduction (Cont.)

- ▶ Each specific type of `Animal` responds to a `move` message in a unique way:
 - a `Fish` might swim three feet
 - a `Frog` might jump five feet
 - a `Bird` might fly ten feet.
- ▶ The program issues the same message (i.e., `move`) to each animal object, but each object knows how to modify its x-y coordinates appropriately for its specific type of movement.
- ▶ Relying on `each object` to know how to “`do the right thing`” in response to the same method call is the key concept of polymorphism.
- ▶ `The same message sent to a variety of objects has “many forms” of results—hence` the term polymorphism.



10.1 Introduction (Cont.)

- ▶ With polymorphism, we can design and implement systems that are easily *extensible*
 - New classes can be added with little or no modification to the general portions of the program, as long as the new classes are part of the inheritance hierarchy that the program processes generically.
 - The only parts of a program that must be altered to accommodate new classes are those that require direct knowledge of the new classes that we add to the hierarchy.

10.1 Introduction (Cont.)

- ▶ Once a class **implements** an **interface**, all objects of that class have an *is-a* relationship with the interface type, and all objects of the class are guaranteed to provide the **functionality** described by the interface.
- ▶ Interfaces are particularly useful for **assigning common functionality** to possibly unrelated classes.
 - Allows objects of unrelated classes to be processed polymorphically—objects of classes that implement the same interface can respond to all of the interface method calls.

10.1 Introduction (Cont.)

- ▶ An **interface** describes a set of methods that can be called on an object, but **does not provide concrete implementations for all the methods**.
- ▶ You can declare classes that **implement** (i.e., provide concrete implementations for the methods of) **one or more** interfaces.
- ▶ Each interface method must be declared in all the classes that explicitly implement the interface.



10.2 Polymorphism Examples

- ▶ Example: Quadrilaterals(四边形)
 - If **Rectangle** is derived from **Quadrilateral**, then a **Rectangle** object is a more specific version of a **Quadrilateral**.
 - Any operation that can be performed on a **Quadrilateral** can also be performed on a **Rectangle**.
 - These operations can also be performed on other **Quadrilaterals**, such as **Squares**, **Parallelograms** (平行四边形) and **Trapezoids**(菱形) .
 - Polymorphism occurs when a program invokes a method through a superclass **Quadrilateral** variable—at execution time, the correct subclass version of the method is called, based on the type of the reference stored in the superclass variable.



10.2 Polymorphism Examples (Cont.)

- ▶ Example: Space Objects in a Video Game
 - A video game manipulates objects of classes **Martian**(火星), **Venusian** (金星), **Plutonian** (冥王星), **Spaceship** (宇宙飞船) and **LaserBeam**. Each inherits from **SpaceObject** and overrides its **draw** method.
 - A screen manager maintains a collection of references to objects of the various classes and periodically sends each object the same message—namely, **draw**.
 - Each object responds in a unique way.
 - A **Martian** object might draw itself in red with green eyes and the appropriate number of antennae.
 - A **Spaceship** object might draw itself as a bright silver flying saucer.
 - A **LaserBeam** object might draw itself as a bright red beam across the screen.
 - The same message (in this case, **draw**) sent to a variety of objects has “many forms” of results.



10.2 Polymorphism Examples (Cont.)

- ▶ A screen manager might use polymorphism to facilitate adding new classes to a system with minimal modifications to the system's code.
- ▶ To add new objects to our video game:
 - Build a class that extends **SpaceObject** and provides its own **draw** method implementation.
 - When objects of that class appear in the **SpaceObject** collection, the screen manager code invokes method **draw**, exactly as it does for every other object in the collection, regardless of its type.
 - So the new objects simply “**plug right in**” without any modification of the screen manager code by the programmer.



Software Engineering Observation 10.1

Polymorphism enables you to deal in generalities and let the execution-time environment handle the specifics. You can command objects to behave in manners appropriate to those objects, without knowing their types (as long as the objects belong to the same inheritance hierarchy).



Software Engineering Observation 10.2

Polymorphism promotes extensibility: Software that invokes polymorphic behavior is independent of the object types to which messages are sent. New object types that can respond to existing method calls can be incorporated into a system without modifying the base system. Only client code that instantiates new objects must be modified to accommodate new types.



10.3 Demonstrating Polymorphic Behavior

- ▶ In the next example, we aim a superclass reference at a subclass object.
 - Invoking a method on a subclass object via a superclass reference invokes the subclass functionality
 - The type of the referenced object, not the type of the variable, determines which method is called



10.3 Demonstrating Polymorphic Behavior (Cont.)

- ▶ This example demonstrates that an object of a subclass can be treated as an object of its superclass, enabling various interesting manipulations.
- ▶ A program can create an array of superclass variables that refer to objects of many subclass types.
 - Allowed because each subclass object *is an* object of its superclass.



10.3 Demonstrating Polymorphic Behavior (Cont.)

- ▶ A superclass object cannot be treated as a subclass object, because a superclass object is *not* an object of any of its subclasses.
- ▶ The *is-a* relationship applies only up the hierarchy from a subclass to its direct (and indirect) superclasses, and **not down** the hierarchy.
- ▶ The Java compiler *does* allow the **assignment of a superclass reference to a subclass variable** if you explicitly cast the superclass reference to the subclass type
 - A technique known as **downcasting** that enables a program to invoke subclass methods that are not in the superclass.



```
1 // Fig. 10.1: PolymorphismTest.java
2 // Assigning superclass and subclass references to superclass and
3 // subclass variables.
4
5 public class PolymorphismTest
6 {
7     public static void main( String[] args )
8     {
9         // assign superclass reference to superclass variable
10        CommissionEmployee commissionEmployee = new CommissionEmployee(
11            "Sue", "Jones", "222-22-2222", 10000, .06 );
12
13        // assign subclass reference to subclass variable
14        BasePlusCommissionEmployee basePlusCommissionEmployee =
15            new BasePlusCommissionEmployee(
16                "Bob", "Lewis", "333-33-3333", 5000, .04, 300 );
17
18        // invoke toString on superclass object using superclass variable
19        System.out.printf( "%s %s:\n\n%s\n\n",
20            "Call CommissionEmployee's toString with superclass reference ",
21            "to superclass object", commissionEmployee.toString() );
```

Fig. 10.1 | Assigning superclass and subclass references to superclass and subclass variables. (Part 1 of 3.)

Variable refers to a
CommissionEmployee
object, so that class's
toString method is
called



```
23 // invoke toString on subclass object using subclass variable
24 System.out.printf( "%s %s:\n\n%s\n\n",
25     "Call BasePlusCommissionEmployee's toString with subclass",
26     "reference to subclass object",
27     basePlusCommissionEmployee.toString() );
28
29 // invoke toString on subclass object using superclass variable
30 CommissionEmployee commissionEmployee2 =
31     basePlusCommissionEmployee;
32 System.out.printf( "%s %s:\n\n%s\n\n",
33     "Call BasePlusCommissionEmployee's toString with superclass",
34     "reference to subclass object", commissionEmployee2.toString() );
35 } // end main
36 } // end class PolymorphismTest
```

Variable refers to a BasePlusCommissionEmployee object, so that class's `toString` method is called

Variable refers to a BasePlusCommissionEmployee object, so that class's `toString` method is called

Call `CommissionEmployee's toString` with superclass reference to superclass object:

```
commission employee: Sue Jones
social security number: 222-22-2222
gross sales: 10000.00
commission rate: 0.06
```

Fig. 10.1 | Assigning superclass and subclass references to superclass and subclass variables. (Part 2 of 3.)



Call BasePlusCommissionEmployee's `toString` with subclass reference to subclass object:

```
base-salaried commission employee: Bob Lewis  
social security number: 333-33-3333  
gross sales: 5000.00  
commission rate: 0.04  
base salary: 300.00
```

Call BasePlusCommissionEmployee's `toString` with superclass reference to subclass object:

```
base-salaried commission employee: Bob Lewis  
social security number: 333-33-3333  
gross sales: 5000.00  
commission rate: 0.04  
base salary: 300.00
```

Fig. 10.1 | Assigning superclass and subclass references to superclass and subclass variables. (Part 3 of 3.)



10.3 Demonstrating Polymorphic Behavior (Cont.)

- ▶ When the **compiler** encounters a method call made through a variable, the compiler determines if the method can be called by checking the variable's class type.
- ▶ At **execution time**, the type of the object to which the variable refers determines the actual method to use.
 - This process is called dynamic binding.



10.4 Abstract Classes and Methods

▶ Abstract classes

- Sometimes it's useful to declare classes for which you **never intend to create objects**.
- Used only as superclasses in inheritance hierarchies, so they are sometimes called **abstract superclasses**.
- Cannot be used to instantiate objects—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.
- ▶ An abstract class provides a superclass from which other classes can inherit and thus share a common design.



10.4 Abstract Classes and Methods (Cont.)

- ▶ 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).
- ▶ Abstract superclasses are **too general to create real objects**—they specify only what is common among subclasses.
- ▶ Concrete classes provide the specifics that make it reasonable to instantiate objects.
- ▶ Not all hierarchies contain abstract classes.



10.4 Abstract Classes and Methods (Cont.)

- ▶ Programmers often write client code that uses only abstract superclass types to reduce client code's dependencies on a range of subclass types.
 - 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.



10.4 Abstract Classes and Methods (Cont.)

- ▶ 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 one with keyword **abstract** in its declaration, as in

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

- ▶ Abstract methods do not provide implementations.
- ▶ A class that contains abstract methods must be an abstract class.
- ▶ 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**.



Software Engineering Observation 10.3

An abstract class declares common attributes and behaviors (both abstract and concrete) of the various 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

Failure to implement a superclass's abstract methods in a subclass is a compilation error unless the subclass is also declared abstract.



10.4 Abstract Classes and Methods (Cont.)

- ▶ Cannot instantiate objects of abstract superclasses, but you can use abstract superclasses to **declare variables**
 - These can hold references to objects of any concrete class derived from those abstract superclasses.
 - Programs typically use such variables to manipulate subclass objects polymorphically.
- ▶ Can use abstract superclass names to invoke **static** methods declared in those abstract superclasses.



10.5 Case Study: Payroll System Using Polymorphism

- ▶ Enhanced employee inheritance hierarchy requirements:
 - A company pays its employees on a weekly basis. The employees are of **four types**:
 - **Salaried employees** are paid a fixed weekly salary regardless of the number of hours worked,
 - **hourly employees** are paid by the hour and receive overtime pay (i.e., 1.5 times their hourly salary rate) for all hours worked in excess of 40 hours,
 - **commission employees** are paid a percentage of their sales
 - **base-salaried commission employees** receive a base salary plus a percentage of their sales.
 - For the current pay period, the company has decided to reward **salaried-commission employees by adding 10%** to their base salaries.
 - The company wants to write a Java application that performs its payroll calculations polymorphically.



10.5 Case Study: Payroll System Using Polymorphism (Cont.)

- ▶ abstract class `Employee` represents the general concept of an employee.
- ▶ Subclasses: `SalariedEmployee`, `CommissionEmployee`, `HourlyEmployee` and `BasePlusCommissionEmployee` (an indirect subclass)
- ▶ Fig. 10.2 shows the inheritance hierarchy for our polymorphic employee-payroll application.
- ▶ Abstract class names are italicized in the UML.

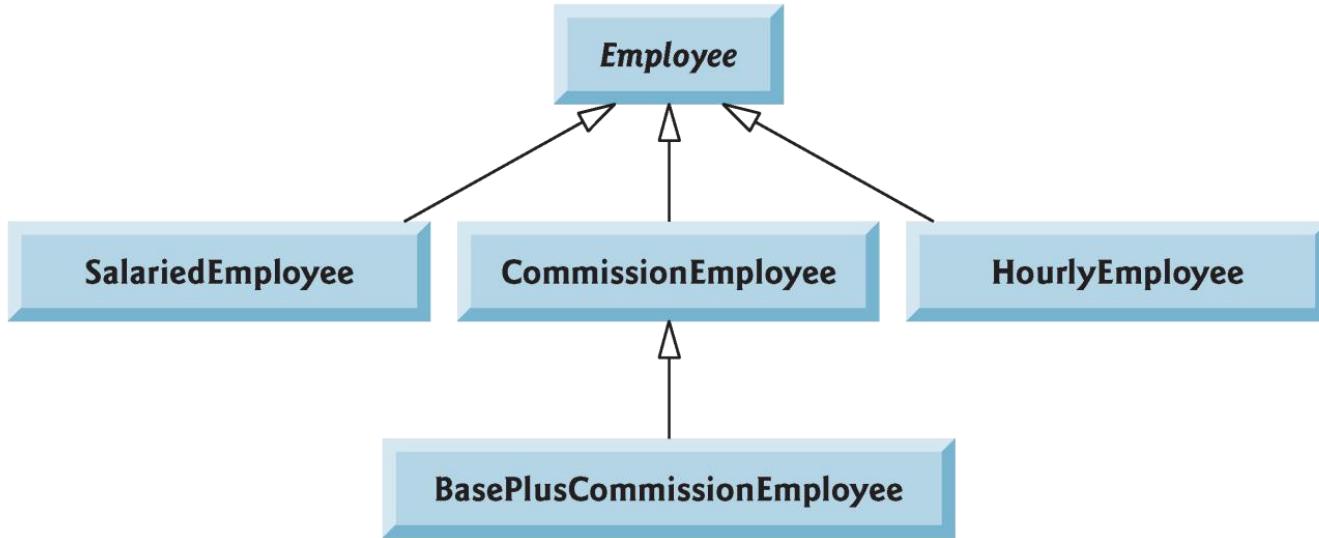


Fig. 10.2 | Employee hierarchy UML class diagram.



```
1 // Fig. 10.4: Employee.java
2 // Employee abstract superclass.
3
4 public abstract class Employee
{
5     private String firstName;
6     private String lastName;
7     private String socialSecurityNumber;
8
9     // three-argument constructor
10    public Employee( String first, String last, String ssn )
11    {
12        firstName = first;
13        lastName = last;
14        socialSecurityNumber = ssn;
15    } // end three-argument Employee constructor
16
17    // set first name
18    public void setFirstName( String first )
19    {
20        firstName = first; // should validate
21    } // end method setFirstName
22
23
```

Fig. 10.4 | Employee abstract superclass. (Part I of 3.)



```
24     // return first name
25     public String getFirstName()
26     {
27         return firstName;
28     } // end method getFirstName
29
30     // set last name
31     public void setLastName( String last )
32     {
33         lastName = last; // should validate
34     } // end method setLastName
35
36     // return last name
37     public String getLastName()
38     {
39         return lastName;
40     } // end method getLastName
41
42     // set social security number
43     public void setSocialSecurityNumber( String ssn )
44     {
45         socialSecurityNumber = ssn; // should validate
46     } // end method setSocialSecurityNumber
47
```

Fig. 10.4 | Employee abstract superclass. (Part 2 of 3.)



```
48     // return social security number
49     public String getSocialSecurityNumber()
50     {
51         return socialSecurityNumber;
52     } // end method getSocialSecurityNumber
53
54     // return String representation of Employee object
55     @Override
56     public String toString()
57     {
58         return String.format( "%s %s\nsocial security number: %s",
59             getFirstName(), getLastName(), getSocialSecurityNumber() );
60     } // end method toString
61
62     // abstract method overridden by concrete subclasses
63     public abstract double earnings(); // no implementation here
64 } // end abstract class Employee
```

This method must be
overridden in
subclasses to make
them concrete

Fig. 10.4 | Employee abstract superclass. (Part 3 of 3.)

```
1 // Fig. 10.5: SalariedEmployee.java
2 // SalariedEmployee concrete class extends abstract class Employee.
3
4 public class SalariedEmployee extends Employee
5 {
6     private double weeklySalary;
7
8     // four-argument constructor
9     public SalariedEmployee( String first, String last, String ssn,
10                           double salary )
11    {
12        super( first, last, ssn ); // pass to Employee constructor
13        setWeeklySalary( salary ); // validate and store salary
14    } // end four-argument SalariedEmployee constructor
15
```

Fig. 10.5 | SalariedEmployee concrete class extends abstract class Employee.
(Part 1 of 3.)



```
16 // set salary
17 public void setWeeklySalary( double salary )
18 {
19     if ( salary >= 0.0 )
20         baseSalary = salary;
21     else
22         throw new IllegalArgumentException(
23             "Weekly salary must be >= 0.0" );
24 } // end method setWeeklySalary
25
26 // return salary
27 public double getWeeklySalary()
28 {
29     return weeklySalary;
30 } // end method getWeeklySalary
31
```

Fig. 10.5 | SalariedEmployee concrete class extends abstract class Employee.
(Part 2 of 3.)



```
32 // calculate earnings; override abstract method earnings in Employee
33 @Override
34 public double earnings()
35 {
36     return getWeeklySalary();
37 } // end method earnings
38
39 // return String representation of SalariedEmployee object
40 @Override
41 public String toString()
42 {
43     return String.format("salaried employee: %s\n%s: $%,.2f",
44             super.toString(), "weekly salary", getWeeklySalary());
45 } // end method toString
46 } // end class SalariedEmployee
```

Fig. 10.5 | SalariedEmployee concrete class extends abstract class Employee.
(Part 3 of 3.)



```
1 // Fig. 10.6: HourlyEmployee.java
2 // HourlyEmployee class extends Employee.
3
4 public class HourlyEmployee extends Employee
5 {
6     private double wage; // wage per hour
7     private double hours; // hours worked for week
8
9     // five-argument constructor
10    public HourlyEmployee( String first, String last, String ssn,
11                           double hourlyWage, double hoursWorked )
12    {
13        super( first, last, ssn );
14        setWage( hourlyWage ); // validate hourly wage
15        setHours( hoursWorked ); // validate hours worked
16    } // end five-argument HourlyEmployee constructor
17
```

Fig. 10.6 | HourlyEmployee class extends Employee. (Part I of 4.)



```
18 // set wage
19 public void setWage( double hourlyWage )
20 {
21     if ( hourlyWage >= 0.0 )
22         wage = hourlyWage;
23     else
24         throw new IllegalArgumentException(
25             "Hourly wage must be >= 0.0" );
26 } // end method setWage
27
28 // return wage
29 public double getWage()
30 {
31     return wage;
32 } // end method getWage
33
```

Fig. 10.6 | HourlyEmployee class extends Employee. (Part 2 of 4.)



```
34 // set hours worked
35 public void setHours( double hoursWorked )
36 {
37     if ( ( hoursWorked >= 0.0 ) && ( hoursWorked <= 168.0 ) )
38         hours = hoursWorked;
39     else
40         throw new IllegalArgumentException(
41             "Hours worked must be >= 0.0 and <= 168.0" );
42 } // end method setHours
43
44 // return hours worked
45 public double getHours()
46 {
47     return hours;
48 } // end method getHours
49
```

Fig. 10.6 | HourlyEmployee class extends Employee. (Part 3 of 4.)



```
50 // calculate earnings; override abstract method earnings in Employee
51 @Override
52 public double earnings()
53 {
54     if ( getHours() <= 40 ) // no overtime
55         return getWage() * getHours();
56     else
57         return 40 * getWage() + ( getHours() - 40 ) * getWage() * 1.5;
58 } // end method earnings
59
60 // return String representation of HourlyEmployee object
61 @Override
62 public String toString()
63 {
64     return String.format( "hourly employee: %s\n%s: $%,.2f; %s: %,.2f",
65                         super.toString(), "hourly wage", getWage(),
66                         "hours worked", getHours() );
67 } // end method toString
68 } // end class HourlyEmployee
```

Fig. 10.6 | HourlyEmployee class extends Employee. (Part 4 of 4.)



```
1 // Fig. 10.7: CommissionEmployee.java
2 // CommissionEmployee class extends Employee.
3
4 public class CommissionEmployee extends Employee
5 {
6     private double grossSales; // gross weekly sales
7     private double commissionRate; // commission percentage
8
9     // five-argument constructor
10    public CommissionEmployee( String first, String last, String ssn,
11        double sales, double rate )
12    {
13        super( first, last, ssn );
14        setGrossSales( sales );
15        setCommissionRate( rate );
16    } // end five-argument CommissionEmployee constructor
17
```

Fig. 10.7 | CommissionEmployee class extends Employee. (Part I of 4.)

```
18 // set commission rate
19 public void setCommissionRate( double rate )
20 {
21     if ( rate > 0.0 && rate < 1.0 )
22         commissionRate = rate;
23     else
24         throw new IllegalArgumentException(
25             "Commission rate must be > 0.0 and < 1.0" );
26 } // end method setCommissionRate
27
28 // return commission rate
29 public double getCommissionRate()
30 {
31     return commissionRate;
32 } // end method getCommissionRate
33
```

Fig. 10.7 | CommissionEmployee class extends Employee. (Part 2 of 4.)



```
34     // set gross sales amount
35     public void setGrossSales( double sales )
36     {
37         if ( sales >= 0.0 )
38             grossSales = sales;
39         else
40             throw new IllegalArgumentException(
41                 "Gross sales must be >= 0.0" );
42     } // end method setGrossSales
43
44     // return gross sales amount
45     public double getGrossSales()
46     {
47         return grossSales;
48     } // end method getGrossSales
49
50     // calculate earnings; override abstract method earnings in Employee
51     @Override
52     public double earnings()
53     {
54         return getCommissionRate() * getGrossSales();
55     } // end method earnings
56
```

Fig. 10.7 | CommissionEmployee class extends Employee. (Part 3 of 4.)



```
57 // return String representation of CommissionEmployee object
58 @Override
59 public String toString()
60 {
61     return String.format( "%s: %s\n%s: $%,.2f; %s: %.2f",
62                         "commission employee", super.toString(),
63                         "gross sales", getGrossSales(),
64                         "commission rate", getCommissionRate() );
65 } // end method toString
66 } // end class CommissionEmployee
```

Fig. 10.7 | CommissionEmployee class extends Employee. (Part 4 of 4.)



```
1 // Fig. 10.8: BasePlusCommissionEmployee.java
2 // BasePlusCommissionEmployee class extends CommissionEmployee.
3
4 public class BasePlusCommissionEmployee extends CommissionEmployee
5 {
6     private double baseSalary; // base salary per week
7
8     // six-argument constructor
9     public BasePlusCommissionEmployee( String first, String last,
10         String ssn, double sales, double rate, double salary )
11    {
12        super( first, last, ssn, sales, rate );
13        setBaseSalary( salary ); // validate and store base salary
14    } // end six-argument BasePlusCommissionEmployee constructor
15
```

Fig. 10.8 | BasePlusCommissionEmployee class extends CommissionEmployee.
(Part 1 of 3.)



```
16 // set base salary
17 public void setBaseSalary( double salary )
18 {
19     if ( salary >= 0.0 )
20         baseSalary = salary;
21     else
22         throw new IllegalArgumentException(
23             "Base salary must be >= 0.0" );
24 } // end method setBaseSalary
25
26 // return base salary
27 public double getBaseSalary()
28 {
29     return baseSalary;
30 } // end method getBaseSalary
31
```

Fig. 10.8 | BasePlusCommissionEmployee class extends CommissionEmployee.
(Part 2 of 3.)



```
32 // calculate earnings; override method earnings in CommissionEmployee
33 @Override
34 public double earnings()
35 {
36     return getBaseSalary() + super.earnings();
37 } // end method earnings
38
39 // return String representation of BasePlusCommissionEmployee object
40 @Override
41 public String toString()
42 {
43     return String.format( "%s %s; %s: $%,.2f",
44         "base-salaried", super.toString(),
45         "base salary", getBaseSalary() );
46 } // end method toString
47 } // end class BasePlusCommissionEmployee
```

Fig. 10.8 | BasePlusCommissionEmployee class extends CommissionEmployee.
(Part 3 of 3.)



10.5.6 Polymorphic Processing, Operator `instanceof` and Downcasting

- ▶ Fig. 10.9 creates an object of each of the four concrete.
 - Manipulates these objects nonpolymorphically, via variables of each object's own type, then polymorphically, using an array of `Employee` variables.
- ▶ While processing the objects polymorphically, the program increases the base salary of each `BasePlusCommissionEmployee` by 10%
 - Requires determining the object's type at execution time.
- ▶ Finally, the program polymorphically determines and outputs the type of each object in the `Employee` array.



```
1 // Fig. 10.9: PayrollSystemTest.java
2 // Employee hierarchy test program.
3
4 public class PayrollSystemTest
5 {
6     public static void main( String[] args )
7     {
8         // create subclass objects
9         SalariedEmployee salariedEmployee =
10            new SalariedEmployee( "John", "Smith", "111-11-1111", 800.00 );
11         HourlyEmployee hourlyEmployee =
12            new HourlyEmployee( "Karen", "Price", "222-22-2222", 16.75, 40 );
13         CommissionEmployee commissionEmployee =
14            new CommissionEmployee(
15                "Sue", "Jones", "333-33-3333", 10000, .06 );
16         BasePlusCommissionEmployee basePlusCommissionEmployee =
17            new BasePlusCommissionEmployee(
18                "Bob", "Lewis", "444-44-4444", 5000, .04, 300 );
19
```

Fig. 10.9 | Employee hierarchy test program. (Part 1 of 7.)



```
20 System.out.println( "Employees processed individually:\n" );
21
22 System.out.printf( "%s\n%s: $%,.2f\n\n",
23     salariedEmployee, "earned", salariedEmployee.earnings() );
24 System.out.printf( "%s\n%s: $%,.2f\n\n",
25     hourlyEmployee, "earned", hourlyEmployee.earnings() );
26 System.out.printf( "%s\n%s: $%,.2f\n\n",
27     commissionEmployee, "earned", commissionEmployee.earnings() );
28 System.out.printf( "%s\n%s: $%,.2f\n\n",
29     basePlusCommissionEmployee,
30     "earned", basePlusCommissionEmployee.earnings() );
31
32 // create four-element Employee array
33 Employee[] employees = new Employee[ 4 ];
34
35 // initialize array with Employees
36 employees[ 0 ] = salariedEmployee;
37 employees[ 1 ] = hourlyEmployee;
38 employees[ 2 ] = commissionEmployee;
39 employees[ 3 ] = basePlusCommissionEmployee;
40
41 System.out.println( "Employees processed polymorphically:\n" );
42
```

Fig. 10.9 | Employee hierarchy test program. (Part 2 of 7.)



```
43     // generically process each element in array employees
44     for ( Employee currentEmployee : employees )
45     {
46         System.out.println( currentEmployee ); // invokes toString
47
48         // determine whether element is a BasePlusCommissionEmployee
49         if ( currentEmployee instanceof BasePlusCommissionEmployee )
50         {
51             // downcast Employee reference to
52             // BasePlusCommissionEmployee reference
53             BasePlusCommissionEmployee employee =
54                 ( BasePlusCommissionEmployee ) currentEmployee;
55
56             employee.setBaseSalary( 1.10 * employee.getBaseSalary() );
57
58             System.out.printf(
59                 "new base salary with 10% increase is: $%,.2f\n",
60                 employee.getBaseSalary() );
61         } // end if
62
63         System.out.printf(
64             "earned $%,.2f\n", currentEmployee.earnings() );
65     } // end for
66
```

Fig. 10.9 | Employee hierarchy test program. (Part 3 of 7.)

```
67     // get type name of each object in employees array
68     for ( int j = 0; j < employees.length; j++ )
69         System.out.printf( "Employee %d is a %s\n", j,
70             employees[ j ].getClass().getName() );
71     } // end main
72 } // end class PayrollSystemTest
```

Fig. 10.9 | Employee hierarchy test program. (Part 4 of 7.)



Employees processed individually:

salaried employee: John Smith
social security number: 111-11-1111
weekly salary: \$800.00
earned: \$800.00

hourly employee: Karen Price
social security number: 222-22-2222
hourly wage: \$16.75; hours worked: 40.00
earned: \$670.00

commission employee: Sue Jones
social security number: 333-33-3333
gross sales: \$10,000.00; commission rate: 0.06
earned: \$600.00

base-salaried commission employee: Bob Lewis
social security number: 444-44-4444
gross sales: \$5,000.00; commission rate: 0.04; base salary: \$300.00
earned: \$500.00

Fig. 10.9 | Employee hierarchy test program. (Part 5 of 7.)



Employees processed polymorphically:

salaried employee: John Smith
social security number: 111-11-1111
weekly salary: \$800.00
earned \$800.00

hourly employee: Karen Price
social security number: 222-22-2222
hourly wage: \$16.75; hours worked: 40.00
earned \$670.00

commission employee: Sue Jones
social security number: 333-33-3333
gross sales: \$10,000.00; commission rate: 0.06
earned \$600.00

base-salaried commission employee: Bob Lewis
social security number: 444-44-4444
gross sales: \$5,000.00; commission rate: 0.04; base salary: \$300.00
new base salary with 10% increase is: \$330.00
earned \$530.00

Fig. 10.9 | Employee hierarchy test program. (Part 6 of 7.)



```
Employee 0 is a SalariedEmployee  
Employee 1 is a HourlyEmployee  
Employee 2 is a CommissionEmployee  
Employee 3 is a BasePlusCommissionEmployee
```

Fig. 10.9 | Employee hierarchy test program. (Part 7 of 7.)



10.5.6 Polymorphic Processing, Operator instanceof and Downcasting (Cont.)

- ▶ All calls to method `toString` and `earnings` are resolved at execution time, based on the type of the object to which `currentEmployee` refers.
 - Known as **dynamic binding** or **late binding**.
 - Java decides which class's `toString` method to call at execution time rather than at compile time
- ▶ A superclass reference can be used to invoke only methods of the superclass—the subclass method implementations are invoked polymorphically.
- ▶ Attempting to invoke a subclass-only method directly on a superclass reference is a compilation error.



Common Programming Error 10.3

*Assigning a superclass variable to a subclass variable
(without an explicit cast) is a compilation error.*



Software Engineering Observation 10.4

If a subclass object's reference has been assigned to a variable of one of its direct or indirect superclasses at execution time, it's acceptable to downcast the reference stored in that superclass variable back to a subclass-type reference. Before performing such a cast, use the instanceof operator to ensure that the object is indeed an object of an appropriate subclass.



Common Programming Error 10.4

When downcasting a reference, a `ClassCastException` occurs if the referenced object at execution time does not have an is-a relationship with the type specified in the cast operator.



10.5.6 Polymorphic Processing, Operator instanceof and Downcasting (Cont.)

- ▶ Every object in Java knows its own class and can access this information through the `getClass` method, which all classes inherit from class `Object`.
 - The `getClass` method returns an object of type `Class` (from package `java.lang`), which contains information about the object's type, including its class name.
 - The result of the `getClass` call is used to invoke `getName` to get the object's class name.



Software Engineering Observation 10.5

Although the actual method that's called depends on the runtime type of the object to which a variable refers, a variable can be used to invoke only those methods that are members of that variable's type, which the compiler verifies.

10.5.7 Summary of the Allowed Assignments Between Superclass and Subclass Variables



- ▶ There are four ways to assign superclass and subclass references to variables of superclass and subclass types.
 1. Assigning a superclass reference to a superclass variable is straightforward.
 2. Assigning a subclass reference to a subclass variable is straightforward.
 3. Assigning a subclass reference to a superclass variable is safe, because the subclass object *is an object of its superclass*.
 - The superclass variable can be used to refer only to superclass members.
 4. Attempting to assign a superclass reference to a subclass variable is a compilation error.



10.6 final Methods and Classes

- ▶ A **final method** in a superclass **cannot be overridden** in a subclass.
 - Methods that are declared **private** are implicitly **final**, because it's not possible to override them in a subclass.
 - Methods that are declared **static** are implicitly **final**.
 - A **final** method's declaration can never change, so all subclasses use the same method implementation, and calls to **final** methods are resolved at compile time—this is known as **static binding**.



10.6 final Methods and Classes (Cont.)

- ▶ A **final class** cannot be a superclass (i.e., a class cannot extend a **final** class).
 - All methods in a **final** class are implicitly **final**.
- ▶ Class **String** is an example of a **final** class.
 - If you were allowed to create a subclass of **String**, objects of that subclass could be used wherever **Strings** are expected.
 - Since class **String** cannot be extended, programs that use **Strings** can rely on the functionality of **String** objects as specified in the Java API.
 - Making the class **final** also prevents programmers from creating subclasses that might bypass security restrictions.



Common Programming Error 10.5

Attempting to declare a subclass of a `final` class is a compilation error.



Software Engineering Observation 10.6

In the Java API, the vast majority of classes are not declared final. This enables inheritance and polymorphism. However, in some cases, it's important to declare classes final—typically for security reasons.



10.7 Case Study: Creating and Using Interfaces

- ▶ Interfaces offer a capability requiring that **unrelated** classes implement a set of common methods.
- ▶ Interfaces define and standardize the ways in which things such as people and systems can interact with one another.
 - Example: The controls on a radio serve as an interface between radio users and a radio's internal components.
 - Can perform only a limited set of operations (e.g., change the station, adjust the volume, choose between AM and FM)
 - Different radios may implement the controls in different ways (e.g., using push buttons, dials, voice commands).



10.7 Case Study: Creating and Using Interfaces (Cont.)

- ▶ The interface specifies *what* operations a radio must permit users to perform but does not specify *how* the operations are performed.
- ▶ A Java interface describes a set of methods that can be called on an object.



10.7 Case Study: Creating and Using Interfaces (Cont.)

- ▶ An **interface declaration** begins with the keyword **interface** and contains only constants and **abstract** methods.
 - All interface members must be **public**.
 - Interfaces may not specify any implementation details, such as concrete method declarations and instance variables.
 - All methods declared in an interface are implicitly **public abstract** methods.
 - All fields are implicitly **public, static** and **final**.



Good Programming Practice 10.1

According to Chapter 9 of the Java Language Specification, it's proper style to declare an interface's methods without keywords `public` and `abstract`, because they're redundant in interface method declarations. Similarly, constants should be declared without keywords `public`, `static` and `final`, because they, too, are redundant.



10.7 Case Study: Creating and Using Interfaces (Cont.)

- ▶ To use an interface, a concrete class must specify that it **implements** the interface and must declare each method in the interface with specified signature.
 - Add the **implements** keyword and the name of the interface to the end of your class declaration's first line.
- ▶ A class that **does not implement** all the methods of the interface is an abstract class and must be declared **abstract**.



10.7 Case Study: Creating and Using Interfaces (Cont.)

- ▶ An interface is often used when disparate (i.e., unrelated) classes need to share common methods and constants.
 - Allows objects of unrelated classes to be processed polymorphically by responding to the same method calls.
 - You can create an interface that describes the desired functionality, then implement this interface in any classes that require that functionality.

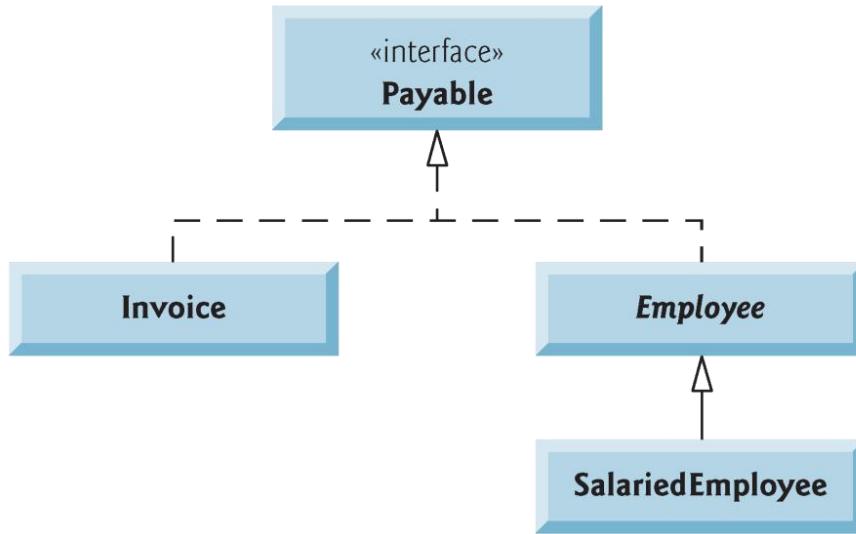


Fig. 10.10 | Payable interface hierarchy UML class diagram.

```
1 // Fig. 10.11: Payable.java
2 // Payable interface declaration.
3
4 public interface Payable
5 {
6     double getPaymentAmount(); // calculate payment; no implementation
7 } // end interface Payable
```

Fig. 10.11 | Payable interface declaration.



10.7.3 Class Invoice

- ▶ Java does not allow subclasses to inherit from more than one superclass, but it allows a class to inherit from one superclass and implement as many interfaces as it needs.
- ▶ To implement more than one interface, use a comma-separated list of interface names after keyword **implements** in the class declaration, as in:

```
public class ClassName extends SuperclassName  
    implements FirstInterface, SecondInterface, ...
```



```
1 // Fig. 10.12: Invoice.java
2 // Invoice class that implements Payable.
3
4 public class Invoice implements Payable
5 {
6     private String partNumber;
7     private String partDescription;
8     private int quantity;
9     private double pricePerItem;
10
11    // four-argument constructor
12    public Invoice( String part, String description, int count,
13                    double price )
14    {
15        partNumber = part;
16        partDescription = description;
17        setQuantity( count ); // validate and store quantity
18        setPricePerItem( price ); // validate and store price per item
19    } // end four-argument Invoice constructor
20
```

Fig. 10.12 | `Invoice` class that implements `Payable`. (Part 1 of 4.)



```
21 // set part number
22 public void setPartNumber( String part )
23 {
24     partNumber = part; // should validate
25 } // end method setPartNumber
26
27 // get part number
28 public String getPartNumber()
29 {
30     return partNumber;
31 } // end method getPartNumber
32
33 // set description
34 public void setPartDescription( String description )
35 {
36     partDescription = description; // should validate
37 } // end method setPartDescription
38
39 // get description
40 public String getPartDescription()
41 {
42     return partDescription;
43 } // end method getPartDescription
44
```

Fig. 10.12 | `Invoice` class that implements `Payable`. (Part 2 of 4.)



```
45 // set quantity
46 public void setQuantity( int count )
47 {
48     if ( count >= 0 )
49         quantity = count;
50     else
51         throw new IllegalArgumentException( "Quantity must be >= 0" );
52 } // end method setQuantity
53
54 // get quantity
55 public int getQuantity()
56 {
57     return quantity;
58 } // end method getQuantity
59
60 // set price per item
61 public void setPricePerItem( double price )
62 {
63     if ( price >= 0.0 )
64         pricePerItem = price;
65     else
66         throw new IllegalArgumentException(
67             "Price per item must be >= 0" );
68 } // end method setPricePerItem
```

Fig. 10.12 | `Invoice` class that implements `Payable`. (Part 3 of 4.)



```
69
70     // get price per item
71     public double getPricePerItem()
72     {
73         return pricePerItem;
74     } // end method getPricePerItem
75
76     // return String representation of Invoice object
77     @Override
78     public String toString()
79     {
80         return String.format( "%s: \n%s: %s (%s) \n%s: %d \n%s: $%,.2f",
81             "invoice", "part number", getPartNumber(), getPartDescription(),
82             "quantity", getQuantity(), "price per item", getPricePerItem() );
83     } // end method toString
84
85     // method required to carry out contract with interface Payable
86     @Override
87     public double getPaymentAmount()
88     {
89         return getQuantity() * getPricePerItem(); // calculate total cost
90     } // end method getPaymentAmount
91 } // end class Invoice
```

Fig. 10.12 | Invoice class that implements Payable. (Part 4 of 4.)



Software Engineering Observation 10.7

All objects of a class that implement multiple interfaces have the is-a relationship with each implemented interface type.



```
1 // Fig. 10.13: Employee.java
2 // Employee abstract superclass that implements Payable.
3
4 public abstract class Employee implements Payable
5 {
6     private String firstName;
7     private String lastName;
8     private String socialSecurityNumber;
9
10    // three-argument constructor
11    public Employee( String first, String last, String ssn )
12    {
13        firstName = first;
14        lastName = last;
15        socialSecurityNumber = ssn;
16    } // end three-argument Employee constructor
17
18    // set first name
19    public void setFirstName( String first )
20    {
21        firstName = first; // should validate
22    } // end method setFirstName
23
```

Fig. 10.13 | Employee class that implements Payable. (Part I of 3.)



```
24     // return first name
25     public String getFirstName()
26     {
27         return firstName;
28     } // end method getFirstName
29
30     // set last name
31     public void setLastName( String last )
32     {
33         lastName = last; // should validate
34     } // end method setLastName
35
36     // return last name
37     public String getLastName()
38     {
39         return lastName;
40     } // end method getLastName
41
42     // set social security number
43     public void setSocialSecurityNumber( String ssn )
44     {
45         socialSecurityNumber = ssn; // should validate
46     } // end method setSocialSecurityNumber
47
```

Fig. 10.13 | Employee class that implements Payable. (Part 2 of 3.)



```
48     // return social security number
49     public String getSocialSecurityNumber()
50     {
51         return socialSecurityNumber;
52     } // end method getSocialSecurityNumber
53
54     // return String representation of Employee object
55     @Override
56     public String toString()
57     {
58         return String.format( "%s %s\nsocial security number: %s",
59             getFirstName(), getLastName(), getSocialSecurityNumber() );
60     } // end method toString
61
62     // Note: We do not implement Payable method getPaymentAmount here so
63     // this class must be declared abstract to avoid a compilation error.
64 } // end abstract class Employee
```

Fig. 10.13 | Employee class that implements Payable. (Part 3 of 3.)



Software Engineering Observation 10.8

When a method parameter is declared with a superclass or interface type, the method processes the object received as an argument polymorphically.



Software Engineering Observation 10.9

Using a superclass reference, we can polymorphically invoke any method declared in the superclass and its superclasses (e.g., class Object). Using an interface reference, we can polymorphically invoke any method declared in the interface, its superinterfaces (one interface can extend another) and in class Object—a variable of an interface type must refer to an object to call methods, and all objects have the methods of class Object.



```
1 // Fig. 10.14: SalariedEmployee.java
2 // SalariedEmployee class extends Employee, which implements Payable.
3
4 public class SalariedEmployee extends Employee
5 {
6     private double weeklySalary;
7
8     // four-argument constructor
9     public SalariedEmployee( String first, String last, String ssn,
10         double salary )
11    {
12        super( first, last, ssn ); // pass to Employee constructor
13        setWeeklySalary( salary ); // validate and store salary
14    } // end four-argument SalariedEmployee constructor
15
```

Fig. 10.14 | SalariedEmployee class that implements interface Payable method
getPaymentAmount. (Part 1 of 3.)



```
16 // set salary
17 public void setWeeklySalary( double salary )
18 {
19     if ( salary >= 0.0 )
20         baseSalary = salary;
21     else
22         throw new IllegalArgumentException(
23             "Weekly salary must be >= 0.0" );
24 } // end method setWeeklySalary
25
26 // return salary
27 public double getWeeklySalary()
28 {
29     return weeklySalary;
30 } // end method getWeeklySalary
31
```

Fig. 10.14 | SalariedEmployee class that implements interface Payable method
getPaymentAmount. (Part 2 of 3.)



```
32 // calculate earnings; implement interface Payable method that was
33 // abstract in superclass Employee
34 @Override
35 public double getPaymentAmount()
36 {
37     return getWeeklySalary();
38 } // end method getPaymentAmount
39
40 // return String representation of SalariedEmployee object
41 @Override
42 public String toString()
43 {
44     return String.format("salaried employee: %s\n%s: $%,.2f",
45     super.toString(), "weekly salary", getWeeklySalary());
46 } // end method toString
47 } // end class SalariedEmployee
```

Fig. 10.14 | SalariedEmployee class that implements interface Payable method
getPaymentAmount. (Part 3 of 3.)



10.7.5 Modifying Class SalariedEmployee for Use in the Payable Hierarchy (Cont.)

- ▶ Objects of any subclasses of a class that **implements** an interface can also be thought of as objects of the interface type.
- ▶ Thus, just as we can assign the reference of a **SalariedEmployee** object to a superclass **Employee** variable, we can assign the reference of a **SalariedEmployee** object to an interface **Payable** variable.
- ▶ **Invoice** implements **Payable**, so an **Invoice** object also *is a Payable object, and we can assign the reference of an Invoice object to a Payable variable.*



```
1 // Fig. 10.15: PayableInterfaceTest.java
2 // Tests interface Payable.
3
4 public class PayableInterfaceTest
5 {
6     public static void main( String[] args )
7     {
8         // create four-element Payable array
9         Payable[] payableObjects = new Payable[ 4 ];
10
11     // populate array with objects that implement Payable
12     payableObjects[ 0 ] = new Invoice( "01234", "seat", 2, 375.00 );
13     payableObjects[ 1 ] = new Invoice( "56789", "tire", 4, 79.95 );
14     payableObjects[ 2 ] =
15         new SalariedEmployee( "John", "Smith", "111-11-1111", 800.00 );
16     payableObjects[ 3 ] =
17         new SalariedEmployee( "Lisa", "Barnes", "888-88-8888", 1200.00 );
18
19     System.out.println(
20         "Invoices and Employees processed polymorphically:\n" );
21 }
```

Fig. 10.15 | Payable interface test program processing *Invoices* and *Employees* polymorphically. (Part I of 3.)

```
22     // generically process each element in array payableObjects
23     for ( Payable currentPayable : payableObjects )
24     {
25         // output currentPayable and its appropriate payment amount
26         System.out.printf( "%s \n%s: $%,.2f\n\n",
27             currentPayable.toString(),
28             "payment due", currentPayable.getPaymentAmount() );
29     } // end for
30 } // end main
31 } // end class PayableInterfaceTest
```

Invoices and Employees processed polymorphically:

```
invoice:
part number: 01234 (seat)
quantity: 2
price per item: $375.00
payment due: $750.00
```

Fig. 10.15 | Payable interface test program processing Invoices and Employees polymorphically. (Part 2 of 3.)



```
invoice:  
part number: 56789 (tire)  
quantity: 4  
price per item: $79.95  
payment due: $319.80
```

```
salaried employee: John Smith  
social security number: 111-11-1111  
weekly salary: $800.00  
payment due: $800.00
```

```
salaried employee: Lisa Barnes  
social security number: 888-88-8888  
weekly salary: $1,200.00  
payment due: $1,200.00
```

Fig. 10.15 | Payable interface test program processing **Invoices** and **Employees** polymorphically. (Part 3 of 3.)



10.7.7 Common Interfaces of the Java API

- ▶ The Java API's interfaces enable you to use your own classes within the frameworks provided by Java, such as comparing objects of your own types and creating tasks that can execute concurrently with other tasks in the same program.
- ▶ Figure 10.16 presents a brief overview of a few of the more popular interfaces of the Java API that we use in *Java How to Program, Ninth Edition*.



Interface	Description
Comparable	Java contains several comparison operators (e.g., <, <=, >, >=, ==, !=) that allow you to compare primitive values. However, these operators <i>cannot</i> be used to compare objects. Interface Comparable is used to allow objects of a class that implements the interface to be compared to one another. Interface Comparable is commonly used for ordering objects in a collection such as an array. We use Comparable in Chapter 20, Generic Collections, and Chapter 21, Generic Classes and Methods.
Serializable	An interface used to identify classes whose objects can be written to (i.e., serialized) or read from (i.e., deserialized) some type of storage (e.g., file on disk, database field) or transmitted across a network. We use Serializable in Chapter 17, Files, Streams and Object Serialization, and Chapter 27, Networking.
Runnable	Implemented by any class for which objects of that class should be able to execute in parallel using a technique called multithreading (discussed in Chapter 26, Multithreading). The interface contains one method, run, which describes the behavior of an object when executed.

Fig. 10.16 | Common interfaces of the Java API. (Part 1 of 2.)



Interface	Description
GUI event-listener interfaces	You work with graphical user interfaces (GUIs) every day. In your web browser, you might type the address of a website to visit, or you might click a button to return to a previous site. The browser responds to your interaction and performs the desired task. Your interaction is known as an event, and the code that the browser uses to respond to an event is known as an event handler. In Chapter 14, GUI Components: Part 1, and Chapter 25, GUI Components: Part 2, you'll learn how to build GUIs and event handlers that respond to user interactions. Event handlers are declared in classes that implement an appropriate event-listener interface. Each event-listener interface specifies one or more methods that must be implemented to respond to user interactions.
SwingConstants	Contains a set of constants used in GUI programming to position GUI elements on the screen. We explore GUI programming in Chapters 14 and 25.

Fig. 10.16 | Common interfaces of the Java API. (Part 2 of 2.)



10.8 Java SE 8 Interface Enhancements(Cont.)

▶ default Interface Methods

- As of Java SE 8, interfaces also may contain **public default methods with *concrete* default implementations** that specify *how* operations are performed when an implementing class does not override the methods.



10.8 Java SE 8 Interface Enhancements(Cont.)

► static Interface Methods

- As of Java SE 8, interfaces also may contain static methods with *concrete* default implementations

► Functional Interface

- any interface containing only one abstract method is known as a functional interface



```
public interface InterfaceA {  
    static void showStatic() {  
        System.out.println("InterfaceA++showStatic");  
    }  
  
    default void showDefault() {  
        System.out.println("InterfaceA ++showDefault");  
    }  
}  
class InterfaceAImpl implements InterfaceA{  
}
```



10.8 Java SE 8 Interface Enhancements(Cont.)

- ▶ **Java SE 9 private Interface Methods**
- ▶ As of Java SE 9, you can declare helper methods in *interfaces* via private interface methods.
- ▶ An interface's private instance methods can be called directly (i.e., without an object reference) only by the interface's other instance methods



Common Programming Error 10.7

Including the default keyword in a private interface method's declaration is a compilation error—default methods must be public.

10.10 private Constructors

- ▶ Preventing object instantiation
- ▶ Sharing initialization code in constructors
- ▶ Factory methods
 - Force client code to use so-called “factory methods” to create objects.



10.11 Program to an Interface, Not an Implementation

- ▶ Implementation inheritance is best for small numbers of tightly coupled classes
- ▶ Interface inheritance is best for flexibility

10.12 (Optional) GUI and Graphics Case Study: Drawing with Polymorphism

