Polymorphism I

CS102A Lecture 12

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Objectives

- Polymorphism
- Override
- Abstract and concrete classes
- Determine an object's type
- Interface

Polymorphism

- The word polymorphism is used in various disciplines to describe situations where something occurs in several different forms.

Biology example: About 6% of the South American population of jaguars are dark-morph jaguars.

Polymorphism in OOP

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- In Java, *polymorphism* is the ability of an object to take on many forms.
- Objects of different types can be accessed through the same interface. Each type can provide its own, independent implementation of this interface.
  - Suppose we create a program that simulates the movement of several types of animals for a biological study. Classes `Fish`, `Frog` and `Bird` represent three types of animals under study.
  - Each class extends superclass `Animal`, which contains a method move and maintains an animal's current `location` as x-y coordinates. Each subclass implements (*overrides*) method `move`.

Polymorphism in OOP

- Each specific type of `Animal` responds to a `move` message in a unique way.
  - A fish might swim 3 feet.
  - A frog might jump 5 feet.
  - A bird might fly 10 feet.

Polymorphism in OOP

- An object of subclass can be treated as an object of the super class.
- 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*.

Polymorphism in OOP

- Polymorphism enables you to write programs to process objects that share the same superclass *as if* they're all objects of the superclass.
- With polymorphism, we can design and implement *extensible* systems.
  - 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 (e.g., the part that creates the corresponding objects).

Another example: Quadrilaterals

- If `Rectangle` is derived from `Quadrilateral`, then a `Rectangle` object is a more specific version of a `Quadrilateral`.
- Any operation (e.g., calculating area) that can be performed on a `Quadrilateral` can also be performed on a `Rectangle`.
- These operations can also be performed on other `Quadrilateral`s, such as `Squares`, `Parallelograms` and `Trapezoids`.
- *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 exact type of the object.

Polymorphic behavior

- All Java objects are *polymorphic* since any object will pass the *IS-A* test for at least their own type and the class `Object`.
  - A bird is an instance of `Bird` class, also an instance of `Animal` and `Object`.
- Earlier, when we write programs, we aim super class variables at superclass objects and subclass variables at subclass objects


```
1 CommissionEmployee employee1 = new CommissionEmployee(...);
2 BasePlusCommissionEmployee employee2 = new BasePlusCommissionEmployee
      (...);
```

Such assignments are natural.

Polymorphic behavior

- In Java, we can also **aim a superclass reference at a subclass object** (the most common use of polymorphism).

```
CommissionEmployee employee = new BasePlusCommissionEmployee(...);
```

This is totally fine due to the *is-a* relationship (an instance of the subclass is also an instance of superclass)

```
BasePlusCommissionEmployee employee = new CommissionEmployee(...);
```

This will not compile, the is-a relationship only applies up the class hierarchy.

Polymorphic behavior

- Then the question comes...

```
1 CommissionEmployee employee = new BasePlusCommissionEmployee(...);
2 double earnings = employee.earnings();
```

- Question: Which version of `earnings()` will be invoked? The one in the superclass or the one overridden by the subclass?
  - Which method is called is determined by the type of the *referenced object*, not the type of the variable.
  - When a superclass variable contains a reference to a subclass object, and that reference is used to call a method, the subclass version of the method is called.

Demo

```java
// Assigning superclass and subclass references to superclass and
// subclass variables.

public class PolymorphismTest {
  public static void main(String[] args) {
    // assign superclass reference to superclass variable
    CommissionEmployee commissionEmployee = new CommissionEmployee(
      "Sue", "Jones", "222-22-2222", 10000, .06);

    // assign subclass reference to subclass variable
    BasePlusCommissionEmployee basePlusCommissionEmployee =
      new BasePlusCommissionEmployee(
      "Bob", "Lewis", "333-33-3333", 5000, .04, 300);
```

Demo

```
11      // invoke toString on superclass object using superclass variable
12      System.out.printf("%s %s:%n%n%s%n%n",
13        "Call CommissionEmployee's toString with superclass reference ",
14        "to superclass object", commissionEmployee.toString());
15      // invoke toString on subclass object using subclass variable
16      System.out.printf("%s %s:%n%n%s%n%n",
17        "Call BasePlusCommissionEmployee's toString with subclass",
18        "reference to subclass object",
19        BasePlusCommissionEmployee.toString());
20      // invoke toString on subclass object using superclass variable
21      CommissionEmployee commissionEmployee2 = basePlusCommissionEmployee;
22      System.out.printf("%s %s:%n%n%s%n",
23        "Call BasePlusCommissionEmployee's toString with superclass",
24        "reference to subclass object", commissionEmployee2.toString());
25    } // end main
26  } // end class PolymorphismTest
```

Demo

```
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

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
```

Demo

```
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
```

Polymorphic behavior

- When the Java compiler encounters a method call made through a variable, it determines if the method can be called by checking the **variable's class type**.
  - If that class contains the proper method declaration (or inherits one), the call will be successfully compiled.
- At execution time, the type of the object to which the variable refers determines the actual method to use (JVM will take care of this).
  - This process is called *dynamic binding*. Binding means "associating method calls to the appropriate method body".

Polymorphic behavior

- What if the subclasses do not override the superclass' method to implement its own specific version (i.e., use the inherited one as is)?
  - Can we force a subclass to override a method inherited from superclass?
  - Yes, we can leverage the power of *abstract class*.

Concrete classes

- All classes we have defined so far provide implementations of every method they declare (some of the implementations can be inherited).
- They are called "*concrete classes*".
- Concrete classes can be used to instantiate objects.

Abstract classes

- Sometimes it's useful to declare "incomplete" classes for which you never intend to create objects.
- Used only as superclasses in inheritance hierarchies.
- They are called "*abstract classes*", cannot be used to instantiate objects.
- Subclasses must declare the "missing pieces" to become concrete classes, from which you can instantiate objects; otherwise, these subclasses, too, will be abstract.

Abstract classes

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- An abstract class provides a superclass from which other classes can inherit and thus share a common design. **Not all hierarchies contain abstract classes**.
- Programmers often write client code that uses only abstract superclass types to reduce client code's dependencies on a range of subclass types (i.e., program in general not in specific).
  - `moveAnAnimal(Animal a) ...` (suppose `Animal` is an abstract class).
  - When called, such a method can receive an object of any concrete class that directly or indirectly extends the abstract superclass `Animal`.

Declaring abstract classes

- You make a class abstract by declaring it with keyword `abstract`.
- An abstract class normally contains one or more *abstract method*s, which are declared with the keyword `abstract` and provides no implementations.

```
1 public abstract class Animal {
2     public abstract void move(); // Be careful, no brackets {}
3     // ...
4 }
```

Abstract method

```java
public abstract class Animal {
    public abstract void move();
}
```

- Abstract methods have the same visibility rules as normal methods, except that they cannot be `private`.
  - Private abstract methods make no sense since abstract methods are intended to be overridden by subclasses.
- Abstract methods have no implementations because the abstract classes are too general and only specify the common interfaces of subclasses.
  - Think about this: How can an `Animal` class provide an appropriate implementation for `move()` method without knowing the specific type of the animal? Every type of animal moves in a different way.

Abstract method

- A class that contains `abstract` methods must be declared as `abstract` even if that class contains some *concrete method*s.
- If a subclass does not implement all abstract methods it inherits from the superclass, the subclass must also be declared as `abstract` and thus **cannot be used to instantiate objects**.
- Constructors and `static` methods cannot be declared `abstract` (constructors are not inherited, non-`private static` methods are inherited but cannot be overridden).

Abstract class

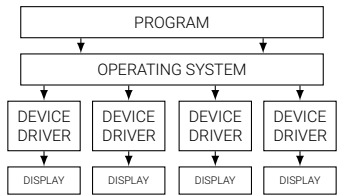
- Although abstract classes cannot be used to instantiate objects, they can be used to declare variables.
- Abstract superclass variables can hold references to objects of any concrete class derived from them.

```
1 Animal animal = new Frog(...); // assuming Animal is abstract
```

- Such practice is commonly adopted to manipulate objects polymorphically. Note that we can use abstract superclass names to invoke static methods declared in those abstract superclasses.

The usefulness of polymorphism

- Very effective for implementing layered software systems.
- Example: Operating systems (OS) and device drivers.
- Device drivers control all communication between the OS and the devices.
- A write message sent to a device-driver object is interpreted in the context of that driver and how it manipulates devices of a specific type.
- 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 (i.e., read/write commands to different devices may have uniformity)



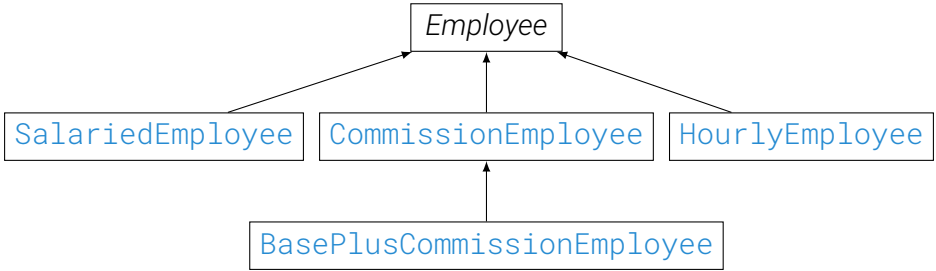
The usefulness of polymorphism

- An object-oriented design of OS might use an abstract superclass to provide an "interface" appropriate for all device drivers.
  - The device-driver methods are declared as `abstract` in the abstract superclass.
  - The implementations of these abstract methods are provided in the subclasses that correspond to the specific types of device drivers.
- New devices are always being developed.
  - When you buy a new device, it comes with a driver provided by the device vendor and is immediately operational after you connect it and install the driver (think about this: do we need to modify the operating system code?)

Case study: A payroll system using polymorphism

- The company pays its four types of employees on a weekly basis.
  - Salaried employees get a fixed weekly salary regardless of working hours.
  - Hourly employees are paid for each hour of work and receive overtime pay (i.e., 1.5x their hourly salary rate) for after 40 hours worked.
  - Commission employees are paid a percentage of their sales.
  - Salaried-commission employees get a base salary + 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.

The design: Main classes



The `Employee` abstract class

- Abstract superclass `Employee` declares the "interface": the set of methods that a program can invoke on all `Employee` objects.
  - Each employee has a first name, a last name and a social security number. This applies to all employee types.
  - Set and get methods for each field. These methods are concrete and the same for all employee types.
  - A constructor for initializing the three fields.
  - Represent the employee's basic information as a string.
  - `earnings()`: abstract method that needs to be implemented by the subclasses (the `Employee` class does not have enough information to do the calculation).

The `Employee` abstract class

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```java
// Employee abstract superclass.
public abstract class Employee {
  private final String firstName;
  private final String lastName;
  private final String socialSecurityNumber;

  // constructor
  public Employee(String firstName, String lastName,
      String socialSecurityNumber)  {
    this.firstName = firstName;
    this.lastName = lastName;
    this.socialSecurityNumber = socialSecurityNumber;
  }

  public String getFirstName() { return firstName; }
  public String getLastName() { return lastName; }
```

The Employee abstract class

```
17    public String getSocialSecurityNumber() {
18      return socialSecurityNumber;
19    }
20
21    // return String representation of Employee object
22    @Override
23    public String toString() {
24      return String.format("%s %s%nsocial security number: %s",
25        getFirstName(), getLastName(), getSocialSecurityNumber());
26    }
27
28    // abstract method must be overridden by concrete subclasses
29    public abstract double earnings(); // no implementation here
30    } // end abstract class Employee
31  } // end abstract class Employee
```

The `SalariedEmployee` class

- Defines a new field `weeklySalary`, provides the corresponding get and set methods. Provides a constructor, and overrides the `earnings` and `toString` methods.

```
1  // SalariedEmployee concrete class extends abstract class Employee.
2  public class SalariedEmployee extends Employee {
3    private double weeklySalary;
4
5    // constructor
6    public SalariedEmployee(String firstName, String lastName,
7        String socialSecurityNumber, double weeklySalary) {
8      super(firstName, lastName, socialSecurityNumber);
9
10     if (weeklySalary < 0.0)
11       throw new IllegalArgumentException("Weekly salary must be >= 0.0");
12     this.weeklySalary = weeklySalary;
13   }
```

The SalariedEmployee class

```
14    // set salary
15    public void setWeeklySalary(double weeklySalary) {
16      if (weeklySalary < 0.0)
17        throw new IllegalArgumentException(
18          "Weekly salary must be >= 0.0");
19
20      this.weeklySalary = weeklySalary;
21    }
22
23    // return salary
24    public double getWeeklySalary() {
25      return weeklySalary;
26    }
```

The SalariedEmployee class

```
27    // calculate earnings; override abstract method earnings in Employee
28    @Override
29    public double earnings() {
30      return getWeeklySalary();
31    }
32
33    // return String representation of SalariedEmployee object
34    @Override
35    public String toString() {
36      return String.format("salaried employee: %s%n%s: $%,.2f",
37        super.toString(), "weekly salary", getWeeklySalary());
38    }
39  } // end class SalariedEmployee
```

The `CommissionEmployee` class

- Defines two new fields `grossSales` and `commissionRate`, provides the corresponding get and set methods. Provides a constructor, and overrides the `earnings` and `toString` methods.

```
1  // CommissionEmployee class extends Employee.
2  public class CommissionEmployee extends Employee {
3    private double grossSales; // gross weekly sales
4    private double commissionRate; // commission percentage
5
6    // constructor
7    public CommissionEmployee(String firstName, String lastName,
8        String socialSecurityNumber, double grossSales,
9        double commissionRate) {
10     super(firstName, lastName, socialSecurityNumber);
```

The CommissionEmployee class

```
11      if (commissionRate <= 0.0 || commissionRate >= 1.0) // validate
12        throw new IllegalArgumentException(
13          "Commission rate must be > 0.0 and < 1.0");
14
15      if (grossSales < 0.0) // validate
16        throw new IllegalArgumentException("Gross sales must be >= 0.0");
17      this.grossSales = grossSales;
18      this.commissionRate = commissionRate;
19    }
20
21    // set gross sales amount
22    public void setGrossSales(double grossSales) {
23      if (grossSales < 0.0) // validate
24        throw new IllegalArgumentException("Gross sales must be >= 0.0");
25
26      this.grossSales = grossSales;
27    }
```

The CommissionEmployee class

```
28    // return gross sales amount
29    public double getGrossSales() { return grossSales; }
30
31    // set commission rate
32    public void setCommissionRate(double commissionRate) {
33      if (commissionRate <= 0.0 || commissionRate >= 1.0) // validate
34        throw new IllegalArgumentException(
35          "Commission rate must be > 0.0 and < 1.0");
36
37      this.commissionRate = commissionRate;
38    }
39
40    // return commission rate
41    public double getCommissionRate() { return commissionRate; }
```

The CommissionEmployee class

```
42    // calculate earnings; override abstract method earnings in Employee
43    @Override
44    public double earnings() {
45      return getCommissionRate() * getGrossSales();
46    }
47
48    // return String representation of CommissionEmployee object
49    @Override
50    public String toString() {
51      return String.format("%s: %s%n%s: $%,.2f; %s: %.2f",
52        "commission employee", super.toString(),
53        "gross sales", getGrossSales(),
54        "commission rate", getCommissionRate());
55    }
56  } // end class CommissionEmployee
```

The `HourlyEmployee` class

- Defines two new fields `wage` and `hours`, provides the corresponding get and set methods. Provides a constructor, and overrides the `earnings` and `toString` methods.

```
1  // HourlyEmployee class extends Employee.
2  public class HourlyEmployee extends Employee {
3    private double wage; // wage per hour
4    private double hours; // hours worked for week
5
6    // constructor
7    public HourlyEmployee(String firstName, String lastName,
8        String socialSecurityNumber, double wage, double hours) {
9      super(firstName, lastName, socialSecurityNumber);
10
11     if (wage < 0.0) // validate wage
12       throw new IllegalArgumentException("Hourly wage must be >= 0.0");
```

The HourlyEmployee class

```
13      if ((hours < 0.0) || (hours > 168.0)) // validate hours
14        throw new IllegalArgumentException(
15          "Hours worked must be >= 0.0 and <= 168.0");
16
17      this.wage = wage;
18      this.hours = hours;
19    }
20
21    // set wage
22    public void setWage(double wage) {
23    if (wage < 0.0) // validate wage
24      throw new IllegalArgumentException("Hourly wage must be >= 0.0");
25
26      this.wage = wage;
27    }
```

The HourlyEmployee class

```
28    // return wage
29    public double getWage() { return wage; }
30
31    // set hours worked
32    public void setHours(double hours) {
33      if ((hours < 0.0) || (hours > 168.0)) // validate hours
34        throw new IllegalArgumentException(
35          "Hours worked must be >= 0.0 and <= 168.0");
36
37      this.hours = hours;
38    }
39
40    // return hours worked
41    public double getHours() { return hours; }
```

The HourlyEmployee class

```
42    // calculate earnings; override abstract method earnings in Employee
43    @Override
44    public double earnings() {
45      if (getHours() <= 40) // no overtime
46        return getWage() * getHours();
47      else
48        return 40 * getWage() + (getHours() - 40) * getWage() * 1.5;
49    }
50
51    // return String representation of HourlyEmployee object
52    @Override
53    public String toString() {
54      return String.format("hourly employee: %s%n%s: $%,.2f; %s: %,.2f",
55        super.toString(), "hourly wage", getWage(),
56        "hours worked", getHours());
57    }
58  } // end class HourlyEmployee
```

The BasePlusCommissionEmployee class

- Extends CommissionEmployee. Defines a new field baseSalary, provides the corresponding get and set methods. Provides a constructor, and overrides the earnings and toString methods.

```
1  // BasePlusCommissionEmployee class extends CommissionEmployee.
2  public class BasePlusCommissionEmployee extends CommissionEmployee {
3    private double baseSalary; // base salary per week
4
5    // constructor
6    public BasePlusCommissionEmployee(String firstName, String lastName,
7        String socialSecurityNumber, double grossSales,
8        double commissionRate, double baseSalary) {
9      super(firstName, lastName, socialSecurityNumber,
10     grossSales, commissionRate);
11
12     if (baseSalary < 0.0) // validate baseSalary
13       throw new IllegalArgumentException("Base salary must be >= 0.0");
```

The BasePlusCommissionEmployee class

```
14      this.baseSalary = baseSalary;
15    }
16
17    // set base salary
18    public void setBaseSalary(double baseSalary) {
19      if (baseSalary < 0.0) // validate baseSalary
20        throw new IllegalArgumentException("Base salary must be >= 0.0");
21
22      this.baseSalary = baseSalary;
23    }
24
25    // return base salary
26    public double getBaseSalary() { return baseSalary; }
```

The BasePlusCommissionEmployee class

```
27    // calculate earnings; override method earnings in CommissionEmployee
28    @Override
29    public double earnings() { return getBaseSalary() + super.earnings(); }
30
31    // return String representation of BasePlusCommissionEmployee object
32    @Override
33    public String toString() {
34      return String.format("%s %s; %s: $%,.2f",
35        "base-salaried", super.toString(),
36        "base salary", getBaseSalary());
37    }
38  } // end class BasePlusCommissionEmployee
```

Assignments between superclass and subclass variables

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```
1 Employee e = new Employee();
```

```
1 CommissionEmployee e = new CommissionEmployee();
```

```
1 Employee e = new CommissionEmployee();
```

- Which version of method is actually called via `e.toString()`?
  - In this particular case, `CommissionEmployee`'s version is called.

Variable's Type and Object's Type

- Variable is the holder, object is the content
- In our example,

```
1 Employee e = new CommissionEmployee();
```

  - `e` is a variable of `Employee`'s type, but it is carrying a `CommissionEmployee` object's reference.
  - As `Employee` is the superclass of `CommissionEmployee`, this assignment is safe.
  - But for other way round, you need *downcasting* to avoid compilation error.

Putting things together

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```
// Employee hierarchy test program.

public class PayrollSystemTest {
  public static void main(String[] args) {
    // create subclass objects
    SalariedEmployee salariedEmployee =
      new SalariedEmployee("John", "Smith", "111-11-1111", 800.00);
    HourlyEmployee hourlyEmployee =
      new HourlyEmployee("Karen", "Price", "222-22-2222", 16.75, 40);
    CommissionEmployee commissionEmployee =
      new CommissionEmployee(
        "Sue", "Jones", "333-33-3333", 10000, .06);
    BasePlusCommissionEmployee basePlusCommissionEmployee =
      new BasePlusCommissionEmployee(
        "Bob", "Lewis", "444-44-4444", 5000, .04, 300);
```

Putting things together

```
16      System.out.println("Employees processed individually:");
17
18      System.out.printf("%n%s%n%s: $%,.2f%n%n",
19        salariedEmployee, "earned", salariedEmployee.earnings());
20      System.out.printf("%s%n%s: $%,.2f%n%n",
21        hourlyEmployee, "earned", hourlyEmployee.earnings());
22      System.out.printf("%s%n%s: $%,.2f%n%n",
23        commissionEmployee, "earned", commissionEmployee.earnings());
24      System.out.printf("%s%n%s: $%,.2f%n%n",
25        basePlusCommissionEmployee, "earned",
26        basePlusCommissionEmployee.earnings());
27
28      // create four-element Employee array
29      Employee[] employees = new Employee[4];
```

Putting things together

```
30      // initialize array with Employees
31      employees[0] = salariedEmployee;
32      employees[1] = hourlyEmployee;
33      employees[2] = commissionEmployee;
34      employees[3] = basePlusCommissionEmployee;
35
36      System.out.printf("Employees processed polymorphically:%n%n");
37
38      // generically process each element in array employees
39      for (Employee currentEmployee : employees) {
40        System.out.println(currentEmployee); // invokes toString
```

Putting things together

```
41        // determine whether element is a BasePlusCommissionEmployee
42        if (currentEmployee instanceof BasePlusCommissionEmployee) {
43          // downcast Employee reference to
44          // BasePlusCommissionEmployee reference
45          BasePlusCommissionEmployee employee =
46            (BasePlusCommissionEmployee) currentEmployee;
47
48          employee.setBaseSalary(1.10 * employee.getBaseSalary());
49
50          System.out.printf(
51            "new base salary with 10%% increase is: $%,.2f%n",
52            employee.getBaseSalary());
53        } // end if
54
55        System.out.printf("earned $%,.2f%n%n", currentEmployee.earnings());
56      } // end for
```

Putting things together

```
57      // get type name of each object in employees array
58      for (int j = 0; j < employees.length; j++)
59        System.out.printf("Employee %d is a %s%n", j,
60          employees[j].getClass().getName());
61    } // end main
62  } // end class PayrollSystemTest
```

Putting things together

```
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
```

Putting things together

```
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

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
```

Putting things together

```
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

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

Assignments between superclass and subclass variables

- Assigning a superclass object's reference to a superclass variable is natural.
- Assigning a subclass object's reference to a subclass variable is natural.
- Assigning a subclass object's reference to a superclass variable is safe, because the subclass object is also an object of its superclass (Java objects are polymorphic).
  - The superclass variable can be used to refer only to superclass members.
  - If a program refers to subclass-only members through the superclass variable, the compiler reports errors.

Assignments between superclass and subclass variables

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- Attempting to assign a superclass object's reference to a subclass variable is a compilation error.
- To avoid this error, the superclass object's reference must be cast to a subclass type explicitly.
- At execution time, if the object to which the reference refers is not a subclass object, an exception will occur.
- Use the `instanceof` operator to ensure that such a cast is performed only if the object is a subclass object.