



## Chapter 8

### Polymorphism and Abstract Classes

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## Introduction to Polymorphism

- There are three main programming mechanisms that constitute object-oriented programming (OOP)
  - Encapsulation
  - Inheritance
  - Polymorphism
- Polymorphism is the ability to associate many meanings to one method name
  - It does this through a special mechanism known as *late binding* or *dynamic binding*

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## Introduction to Polymorphism

- Inheritance allows a base class to be defined, and other classes derived from it
  - Code for the base class can then be used for its own objects, as well as objects of any derived classes
- Polymorphism allows changes to be made to method definitions in the derived classes, *and have those changes apply to the software written for the base class*

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## Late Binding

- The process of associating a method definition with a method invocation is called *binding*
- If the method definition is associated with its invocation when the code is compiled, that is called *early binding*
- If the method definition is associated with its invocation when the method is invoked (at run time), that is called *late binding* or *dynamic binding*

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## Late Binding

- Java uses late binding for all methods (except private, **final**, and static methods)
- Because of late binding, a method can be written in a base class to perform a task, even if portions of that task aren't yet defined
- For an example, the relationship between a base class called **Sale** and its derived class **DiscountSale** will be examined

## The **Sale** and **DiscountSale** Classes

- The **Sale** class contains two instance variables
  - **name**: the name of an item (**String**)
  - **price**: the price of an item (**double**)
- It contains three constructors
  - A no-argument constructor that sets **name** to "**No name yet**", and price to **0.0**
  - A two-parameter constructor that takes in a **String** (for **name**) and a **double** (for **price**)
  - A copy constructor that takes in a **Sale** object as a parameter

## The **Sale** and **DiscountSale** Classes

- The **Sale** class also has a set of accessors (**getName**, **getPrice**), mutators (**setName**, **setPrice**), overridden **equals** and **toString** methods, and a static **announcement** method
- The **Sale** class has a method **bill**, that determines the bill for a sale, which simply returns the price of the item
- It has two methods, **equalDeals** and **lessThan**, each of which compares two sale objects *by comparing their bills* and returns a **boolean** value

## The **Sale** and **DiscountSale** Classes

- The **DiscountSale** class inherits the instance variables and methods from the **Sale** class
- In addition, it has its own instance variable, **discount** (a percent of the **price**), and its own suitable constructor methods, accessor method (**getDiscount**), mutator method (**setDiscount**), overridden **toString** method, and static **announcement** method
- The **DiscountSale** class has its own **bill** method which computes the bill as a function of the **discount** and the **price**

## The Sale and DiscountSale Classes

- The **Sale** class **lessThan** method
  - Note the **bill()** method invocations:

```
public boolean lessThan (Sale otherSale)
{
    if (otherSale == null)
    {
        System.out.println("Error: null object");
        System.exit(0);
    }
    return (bill( ) < otherSale.bill( ));
}
```

## The Sale and DiscountSale Classes

- The **Sale** class **bill()** method:

```
public double bill( )
{
    return price;
}
```

- The **DiscountSale** class **bill()** method:

```
public double bill( )
{
    double fraction = discount/100;
    return (1 - fraction) * getPrice( );
}
```

## The Sale and DiscountSale Classes

- Given the following in a program:

```
. . . .
Sale simple = new sale("floor mat", 10.00);
DiscountSale discount = new
    DiscountSale("floor mat", 11.00, 10);
. . . .
if (discount.lessThan(simple))
    System.out.println("$" + discount.bill() +
        "< " + "$" + simple.bill() +
        " because late-binding works!");
. . . .
```

- Output would be:

```
$9.90 < $10 because late-binding works!
```

## The Sale and DiscountSale Classes

- In the previous example, the **boolean** expression in the **if** statement returns **true**
- As the output indicates, when the **lessThan** method in the **Sale** class is executed, it knows which **bill()** method to invoke
  - The **DiscountSale** class **bill()** method for **discount**, and the **Sale** class **bill()** method for **simple**
- Note that when the **Sale** class was created and compiled, the **DiscountSale** class and its **bill()** method did not yet exist
  - These results are made possible by late-binding

## Pitfall: No Late Binding for Static Methods

- When the decision of which definition of a method to use is made at compile time, that is called *static binding*
  - This decision is made based on the *type of the variable naming the object*
- Java uses static, not late, binding with **private**, **final**, and static methods
  - In the case of **private** and **final** methods, late binding would serve no purpose
  - However, in the case of a static method invoked using a calling object, it does make a difference

## Pitfall: No Late Binding for Static Methods

- The **Sale** class **announcement()** method:

```
public static void announcement( )
{
    System.out.println("Sale class");
}
```

- The **DiscountSale** class **announcement()** method:

```
public static void announcement( )
{
    System.out.println("DiscountSale class");
}
```

## Pitfall: No Late Binding for Static Methods

- In the previous example, the the **simple** (**Sale** class) and **discount** (**DiscountClass**) objects were created
- Given the following assignment:

```
simple = discount;
```

  - Now the two variables point to the same object
  - In particular, a **Sale** class variable names a **DiscountClass** object

## Pitfall: No Late Binding for Static Methods

- Given the invocation:

```
simple.announcement();
```

- The output is:

```
Sale class
```

- Note that here, **announcement** is a static method invoked by a calling object (instead of its class name)
  - Therefore the type of **simple** is determined by its variable name, not the object that it references

## Pitfall: No Late Binding for Static Methods

- There are other cases where a static method has a calling object in a more inconspicuous way
- For example, a static method can be invoked within the definition of a nonstatic method, but without any explicit class name or calling object
- In this case, the calling object is the implicit `this`

## The `final` Modifier

- A *method* marked `final` indicates that it cannot be overridden with a new definition in a derived class
  - If `final`, the compiler can use early binding with the method

```
public final void someMethod() { . . . }
```

- A *class* marked `final` indicates that it cannot be used as a base class from which to derive any other classes

## Late Binding with `toString`

- If an appropriate `toString` method is defined for a class, then an object of that class can be output using

```
System.out.println
```

```
Sale aSale = new Sale("tire gauge", 9.95);  
System.out.println(aSale);
```

- Output produced:

```
tire gauge Price and total cost = $9.95
```

- This works because of late binding

## Late Binding with `toString`

- One definition of the method `println` takes a single argument of type `Object`:

```
public void println(Object theObject)  
{  
    System.out.println(theObject.toString());  
}
```

- In turn, it invokes the version of `println` that takes a `String` argument
- Note that the `println` method was defined before the `Sale` class existed
- Yet, because of late binding, the `toString` method from the `Sale` class is used, not the `toString` from the `Object` class

## An Object knows the Definitions of its Methods

- The type of a class variable determines which method names can be used with the variable
  - However, the object named by the variable determines which definition with the same method name is used
- A special case of this rule is as follows:
  - The type of a class parameter determines which method names can be used with the parameter
  - The argument determines which definition of the method name is used

## Upcasting and Downcasting

- *Upcasting* is when an object of a derived class is assigned to a variable of a base class (or any ancestor class)

```
Sale saleVariable; //Base class
DiscountSale discountVariable = new
    DiscountSale("paint", 15,10); //Derived class
saleVariable = discountVariable; //Upcasting
System.out.println(saleVariable.toString());
```

- Because of late binding, `toString` above uses the definition given in the `DiscountSale` class

## Upcasting and Downcasting

- *Downcasting* is when a type cast is performed from a base class to a derived class (or from any ancestor class to any descendent class)
  - Downcasting has to be done very carefully
  - In many cases it doesn't make sense, or is illegal:

```
discountVariable = //will produce
    (DiscountSale)saleVariable; //run-time error
discountVariable = saleVariable //will produce
    //compiler error
```

- There are times, however, when downcasting is necessary, e.g., inside the `equals` method for a class:

```
Sale otherSale = (Sale)otherObject; //downcasting
```

## Pitfall: Downcasting

- It is the responsibility of the programmer to use downcasting only in situations where it makes sense
  - The compiler does not check to see if downcasting is a reasonable thing to do
- Using downcasting in a situation that does not make sense usually results in a run-time error

## Tip: Checking to See if Downcasting is Legitimate

- Downcasting to a specific type is only sensible if the object being cast is an instance of that type
  - This is exactly what the `instanceof` operator tests for:  
`object instanceof ClassName`
  - It will return true if `object` is of type `ClassName`
  - In particular, it will return true if `object` is an instance of any descendent class of `ClassName`

## A First Look at the `clone` Method

- Every object inherits a method named `clone` from the class `Object`
  - The method `clone` has no parameters
  - It is supposed to return a deep copy of the calling object
- However, the inherited version of the method was not designed to be used as is
  - Instead, each class is expected to override it with a more appropriate version

## A First Look at the `clone` Method

- The heading for the `clone` method defined in the `Object` class is as follows:  
`protected Object clone()`
- The heading for a `clone` method that overrides the `clone` method in the `Object` class can differ somewhat from the heading above
  - A change to a more permissive access, such as from `protected` to `public`, is always allowed when overriding a method definition
  - Changing the return type from `Object` to the type of the class being cloned is allowed because every class is a descendent class of the class `Object`
  - This is an example of a covariant return type

## A First Look at the `clone` Method

- If a class has a copy constructor, the `clone` method for that class can use the *copy constructor* to create the copy returned by the `clone` method

```
public Sale clone()
{
    return new Sale(this);
}
```

and another example:

```
public DiscountSale clone()
{
    return new DiscountSale(this);
}
```

## Pitfall: Sometime the `clone` Method Return Type is `Object`

- Prior to version 5.0, Java did not allow covariant return types
  - There were no changes whatsoever allowed in the return type of an overridden method
- Therefore, the `clone` method for all classes had `Object` as its return type
  - Since the return type of the clone method of the `Object` class was `Object`, the return type of the overriding clone method of any other class was `Object` also

## Pitfall: Sometime the `clone` Method Return Type is `Object`

- Prior to Java version 5.0, the `clone` method for the `Sale` class would have looked like this:

```
public Object clone()
{
    return new Sale(this);
}
```
- Therefore, the result must always be type cast when using a `clone` method written for an older version of Java

```
Sale copy = (Sale)original.clone();
```

## Pitfall: Sometime the `clone` Method Return Type is `Object`

- It is still perfectly legal to use `Object` as the return type for a clone method, even with classes defined after Java version 5.0
  - When in doubt, it causes no harm to include the type cast
  - For example, the following is legal for the clone method of the `Sale` class:

```
Sale copy = original.clone();
```
  - However, adding the following type cast produces no problems:

```
Sale copy = (Sale)original.clone();
```

## Pitfall: Limitations of Copy Constructors

- Although the copy constructor and `clone` method for a class appear to do the same thing, there are cases where only a `clone` will work
- For example, given a method `badcopy` in the class `Sale` that copies an array of sales
  - If this array of sales contains objects from a derived class of `Sale` (i.e., `DiscountSale`), then the copy will be a plain sale, not a true copy

```
b[i] = new Sale(a[i]); //plain Sale object
```



## Pitfall: Limitations of Copy Constructors

- However, if the `clone` method is used instead of the copy constructor, then (because of late binding) a true copy is made, even from objects of a derived class (e.g., `DiscountSale`):  
`b[i] = (a[i].clone()); //DiscountSale object`
  - The reason this works is because the method `clone` has the same name in all classes, and polymorphism works with method names
  - The copy constructors named `Sale` and `DiscountSale` have different names, and polymorphism doesn't work with methods of different names

## Introduction to Abstract Classes

- In Chapter 7, the `Employee` base class and two of its derived classes, `HourlyEmployee` and `SalariedEmployee` were defined
- The following method is added to the `Employee` class
  - It compares employees to see if they have the same pay:  

```
public boolean samePay(Employee other)
{
    return(this.getPay() == other.getPay());
}
```

## Introduction to Abstract Classes

- There are several problems with this method:
  - The `getPay` method is invoked in the `samePay` method
  - There are `getPay` methods in each of the derived classes
  - There is no `getPay` method in the `Employee` class, nor is there any way to define it reasonably without knowing whether the employee is hourly or salaried

## Introduction to Abstract Classes

- The ideal situation would be if there were a way to
  - Postpone the definition of a `getPay` method until the type of the employee were known (i.e., in the derived classes)
  - Leave some kind of note in the `Employee` class to indicate that it was accounted for
- Surprisingly, Java allows this using abstract classes and methods

## Introduction to Abstract Classes

- In order to postpone the definition of a method, Java allows an *abstract method* to be declared
  - An abstract method has a heading, but no method body
  - The body of the method is defined in the derived classes
- The class that contains an abstract method is called an *abstract class*

## Abstract Method

- An abstract method is like a placeholder for a method that will be fully defined in a descendent class
- It has a complete method heading, to which has been added the modifier **abstract**
- It cannot be private
- It has no method body, and ends with a semicolon in place of its body

```
public abstract double getPay();  
public abstract void doIt(int count);
```

## Abstract Class

- A class that has at least one abstract method is called an *abstract class*
  - An abstract class must have the modifier **abstract** included in its class heading:

```
public abstract class Employee  
{  
    private instanceVariables;  
    . . .  
    public abstract double getPay();  
    . . .  
}
```

## Abstract Class

- An abstract class can have any number of abstract and/or fully defined methods
- If a derived class of an abstract class adds to or does not define all of the abstract methods, then it is abstract also, and must add **abstract** to its modifier
- A class that has no abstract methods is called a *concrete class*

## Pitfall: You Cannot Create Instances of an Abstract Class

- An abstract class can only be used to derive more specialized classes
  - While it may be useful to discuss employees in general, in reality an employee must be a salaried worker or an hourly worker
- An abstract class constructor cannot be used to create an object of the abstract class
  - However, a derived class constructor will include an invocation of the abstract class constructor in the form of `super`

## Tip: An Abstract Class Is a Type

- Although an object of an abstract class cannot be created, it is perfectly fine to have a parameter of an abstract class type
  - This makes it possible to plug in an object of any of its descendent classes
- It is also fine to use a variable of an abstract class type, as long as it names objects of its concrete descendent classes only