Chapter 11: Inheritance and Polymorphism

CS2: Data Structures and Algorithms
Colorado State University

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Basic Component: Class

A Class is a software bundle of related states (properties, or variables) and behaviors (methods)

- State is stored in instance variables
- Method exposes behavior
Basic Components

✦ **Class**: *Blueprint* from which objects are created
  – Multiple Object Instances created from a class

✦ **Interface**: A *Contract* between classes and the outside world.
  – When a class *implements* an interface, it *promises* to provide the behavior published by that interface.

✦ **Package**: a *namespace* (directory) for organizing classes and interfaces
Data Encapsulation

✧ An ability of an object to be a container (or capsule) for related properties and methods.
  – Preventing unexpected change or reuse of the content

✧ **Data hiding**
  – Object can shield variables from external access.
    ✦ Private variables
    ✦ Public accessor and mutator methods, with potentially limited capacities, e.g. only read access, or write only valid data.
Data Encapsulation

```java
public class Clock{
    private long time, alarm_time;

    public void setTime(long time){
        this.time = time;
    }
    public void setAlarmTime(long time){
        this.alarm_time = time;
    }
    public long getTime(){return time}
    public long getAlarmTime(){return alarm_time}
    public void noticeAlarm(){ ... /*ring alarm */ }
}
```
Inheritance

✧ The ability of a class to derive properties and behaviors from a previously defined class.

✧ **Relationship** among classes.

✧ Enables **reuse** of software components
  – e.g., java.lang.Object()
  – toString(), equals(), etc.
Example: Inheritance

- Clock
  - Sports Watch
  - Radio Clock
Example: Inheritance – cont.

```java
public class SportsWatch extends Clock {
    private long start_time;
    private long end_time;

    public long getDuration()
    {
        return end_time - start_time;
    }
}
```
Overriding Methods

```java
public class RadioClock extends Clock {
    @Override
    public void noticeAlarm() {
        ring alarm
        turn_on_the_Radio
    }
}
```
Another Example

Suppose you want to define classes to model circles, rectangles, and triangles. These classes have many common features.

What is the best way to design these classes so to avoid redundancy?

The answer is to use inheritance: creating a hierarchy of classes, where common features are shared in higher level classes.
## Superclasses and Subclasses

### GeometricObject

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>color: String</td>
<td>The color of the object (default: white).</td>
</tr>
<tr>
<td>filled: boolean</td>
<td>Indicates whether the object is filled with a color (default: false).</td>
</tr>
<tr>
<td>dateCreated: java.util.Date</td>
<td>The date when the object was created.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+GeometricObject()</td>
<td>Creates a GeometricObject.</td>
</tr>
<tr>
<td>+GeometricObject(color: String, filled: boolean)</td>
<td>Creates a GeometricObject with the specified color and filled values.</td>
</tr>
<tr>
<td>+getColor(): String</td>
<td>Returns the color.</td>
</tr>
<tr>
<td>+setColor(color: String): void</td>
<td>Sets a new color.</td>
</tr>
<tr>
<td>+isFilled(): boolean</td>
<td>Returns the filled property.</td>
</tr>
<tr>
<td>+setFilled(filled: boolean): void</td>
<td>Sets a new filled property.</td>
</tr>
<tr>
<td>+getDateCreated(): java.util.Date</td>
<td>Returns the dateCreated.</td>
</tr>
<tr>
<td>+toString(): String</td>
<td>Returns a string representation of this object.</td>
</tr>
</tbody>
</table>

### Circle

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>radius: double</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+Circle()</td>
<td></td>
</tr>
<tr>
<td>+Circle(radius: double)</td>
<td></td>
</tr>
<tr>
<td>+Circle(radius: double, color: String, filled: boolean)</td>
<td></td>
</tr>
<tr>
<td>+getRadius(): double</td>
<td></td>
</tr>
<tr>
<td>+setWidth(radius: double): void</td>
<td></td>
</tr>
<tr>
<td>+getHeight(): double</td>
<td></td>
</tr>
<tr>
<td>+getArea(): double</td>
<td></td>
</tr>
<tr>
<td>+getPerimeter(): double</td>
<td></td>
</tr>
<tr>
<td>+getDiameter(): double</td>
<td></td>
</tr>
<tr>
<td>+printCircle(): void</td>
<td></td>
</tr>
</tbody>
</table>

### Rectangle

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>width: double</td>
<td></td>
</tr>
<tr>
<td>height: double</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+Rectangle()</td>
<td></td>
</tr>
<tr>
<td>+Rectangle(width: double, height: double)</td>
<td></td>
</tr>
<tr>
<td>+Rectangle(width: double, height: double, color: String, filled: boolean)</td>
<td></td>
</tr>
<tr>
<td>+getWidth(): double</td>
<td></td>
</tr>
<tr>
<td>+setWidth(width: double): void</td>
<td></td>
</tr>
<tr>
<td>+getHeight(): double</td>
<td></td>
</tr>
<tr>
<td>+getArea(): double</td>
<td></td>
</tr>
<tr>
<td>+getPerimeter(): double</td>
<td></td>
</tr>
</tbody>
</table>

### Diagram

![Diagram of GeometricObject, Circle, and Rectangle classes and their methods]

### Code Snippet

```
GeometricObject
- color: String
- filled: boolean
- dateCreated: java.util.Date

+ GeometricObject()
+ GeometricObject(color: String, filled: boolean)
+ getColor(): String
+ setColor(color: String): void
+ isFilled(): boolean
+ setFilled(filled: boolean): void
+ getDateCreated(): java.util.Date
+ toString(): String
```

```
Circle
- radius: double

+ Circle()
+ Circle(radius: double)
+ Circle(radius: double, color: String, filled: boolean)
+ getRadius(): double
+ setRadius(radius: double): void
+ getArea(): double
+ getPerimeter(): double
+ getDiameter(): double
+ printCircle(): void
```

```
Rectangle
- width: double
- height: double

+ Rectangle()
+ Rectangle(width: double, height: double)
+ Rectangle(width: double, height: double, color: String, filled: boolean)
+ getWidth(): double
+ setWidth(width: double): void
+ getHeight(): double
+ setHeight(height: double): void
+ getArea(): double
+ getPerimeter(): double
```

### Run

- CircleFromSimpleGeometricObject
- RectangleFromSimpleGeometricObject
- TestCircleRectangle
Definition: Inheritance

✧ Inheritance:
  Lower level classes get (access to)
certain methods and data from higher level
classes

✧ Data and methods are now defined in one
place (the super class) and used in this
and lower (sub) classes
Are superclass’s Constructor Inherited?

No. They are not inherited.

They are invoked explicitly or implicitly.

Explicitly using the super keyword.

A constructor is used to construct an instance of a class. Unlike data and methods, a superclass's constructors are not inherited in the subclass. They can only be invoked from the subclasses' constructors, using the keyword super.

*If the keyword super is not explicitly used, the superclass's no-arg constructor is automatically invoked.*
A constructor may invoke an overloaded constructor or its superclass’s constructor. If none of them is invoked explicitly, the compiler puts `super()` as the first statement in the constructor. For example,

```
public A() {
    // some statements
}
```

is equivalent to

```
public A() {
    super();
    // some statements
}
```

```
public A(double d) {
    // some statements
}
```

is equivalent to

```
public A(double d) {
    super();
    // some statements
}
```
Using the Keyword super

The keyword super refers to the superclass of the class in which super appears. This keyword can be used in two ways:

✧ To call a superclass constructor
✧ To call a superclass method
CAUTION

You must use the keyword `super` to call the superclass constructor, instead of the superclass constructor’s name.

Java requires that the constructor call `super` appear first in the constructor.
Constructor Chaining

Constructing an instance of a class invokes all the superclasses’ constructors along the inheritance chain. This is known as constructor chaining.

```java
public class Faculty extends Employee {
    public static void main(String[] args) {
        new Faculty();
    }

    public Faculty() {
        System.out.println("(4) Faculty's no-arg constructor is invoked");
    }
}

class Employee extends Person {
    public Employee() {
        this("(2) Invoke Employee’s overloaded constructor");
        System.out.println("(3) Employee's no-arg constructor is invoked");
    }

    public Employee(String s) {
        System.out.println(s);
    }
}

class Person {
    public Person() {
        System.out.println("(1) Person's no-arg constructor is invoked");
    }
}
```

Constructing an instance of a class invokes all the superclasses’ constructors along the inheritance chain. This is known as constructor chaining.
public class Faculty extends Employee {
    public static void main(String[] args) {
        new Faculty();
    }

    public Faculty() {
        System.out.println("(4) Faculty's no-arg constructor is invoked");
    }
}

class Employee extends Person {
    public Employee() {
        this("(2) Invoke Employee's overloaded constructor");
        System.out.println("(3) Employee's no-arg constructor is invoked");
    }

    public Employee(String s) {
        System.out.println(s);
    }
}

class Person {
    public Person() {
        System.out.println("(1) Person's no-arg constructor is invoked");
    }
}

1. Start from the main method
public class Faculty extends Employee {
    public static void main(String[] args) {
        new Faculty();
    }

    public Faculty() {
        System.out.println("(4) Faculty's no-arg constructor is invoked");
    }
}

class Employee extends Person {
    public Employee() {
        this("(2) Invoke Employee's overloaded constructor");
        System.out.println("(3) Employee's no-arg constructor is invoked");
    }

    public Employee(String s) {
        System.out.println(s);
    }
}

class Person {
    public Person() {
        System.out.println("(1) Person's no-arg constructor is invoked");
    }
}
public class Faculty extends Employee {
    public static void main(String[] args) {
        new Faculty();
    }
}

public Faculty() {
    System.out.println("(4) Faculty's no-arg constructor is invoked");
}

class Employee extends Person {
    public Employee() {
        this("(2) Invoke Employee's overloaded constructor");
        System.out.println("(3) Employee's no-arg constructor is invoked");
    }

    public Employee(String s) {
        System.out.println(s);
    }
}

class Person {
    public Person() {
        System.out.println("(1) Person's no-arg constructor is invoked");
    }
}
public class Faculty extends Employee {
    public static void main(String[] args) {
        new Faculty();
    }

    public Faculty() {
        System.out.println("(4) Faculty's no-arg constructor is invoked");
    }
}

class Employee extends Person {
    public Employee() {
        this("(2) Invoke Employee’s overloaded constructor");
        System.out.println("(3) Employee's no-arg constructor is invoked");
    }

    public Employee(String s) {
        System.out.println(s);
    }
}

class Person {
    public Person() {
        System.out.println("(1) Person's no-arg constructor is invoked");
    }
}
public class Faculty extends Employee {
    public static void main(String[] args) {
        new Faculty();
    }

    public Faculty() {
        System.out.println("(4) Faculty's no-arg constructor is invoked");
    }
}

class Employee extends Person {
    public Employee() {
        this("(2) Invoke Employee’s overloaded constructor");
        System.out.println("(3) Employee's no-arg constructor is invoked");
    }

    public Employee(String s) {
        System.out.println(s);
    }
}

class Person {
    public Person() {
        System.out.println("(1) Person's no-arg constructor is invoked");
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}
public class Faculty extends Employee {
    public static void main(String[] args) {
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    public Employee(String s) {
        System.out.println(s);
    }
}

class Person {
    public Person() {
        System.out.println("(1) Person's no-arg constructor is invoked");
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public class Faculty extends Employee {
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    public Faculty() {
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class Employee extends Person {
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    }

    public Employee(String s) {
        System.out.println(s);
    }
}

class Person {
    public Person() {
        System.out.println("(1) Person's no-arg constructor is invoked");
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}
public class Faculty extends Employee {
    public static void main(String[] args) {
        new Faculty();
    }
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    public Faculty() {
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    public Employee(String s) {
        System.out.println(s);
    }
}

class Person {
    public Person() {
        System.out.println("(1) Person's no-arg constructor is invoked");
    }
}

8. Execute println
public class Faculty extends Employee {
    public static void main(String[] args) {
        new Faculty();
    }

    public Faculty() {
        System.out.println("(4) Faculty's no-arg constructor is invoked");
    }
}

class Employee extends Person {
    public Employee() {
        this("(2) Invoke Employee's overloaded constructor");
        System.out.println("(3) Employee's no-arg constructor is invoked");
    }

    public Employee(String s) {
        System.out.println(s);
    }
}

class Person {
    public Person() {
        System.out.println("(1) Person's no-arg constructor is invoked");
    }
}
Example on the Impact of a Superclass without no-arg Constructor

Error: Fruit has no no-arg constructor, so Apple fails:

```java
public class Apple extends Fruit {
}

class Fruit {
    public Fruit(String name) {
        System.out.println("Fruit's constructor is invoked");
    }
}
```
Defining a Subclass

A subclass inherits methods and data from a superclass. You can also:

✦ Add new properties
✦ Add new methods
✦ Override the methods of the superclass
Overriding vs. Overloading

**Overloading** occurs when two or more methods **in the same class** have the same method name but different parameters.

**Overriding** means having two methods with the same method name and parameters (i.e., method signature). One of the methods is in the **parent class** and the other is in the **child class**.
Overriding vs. Overloading

```java
public class Test {
    public static void main(String[] args) {
        A a = new A();
        a.p(10);
        a.p(10.0);
    }
}

class B {
    public void p(double i) {
        System.out.println(i * 2);
    }
}

class A extends B {
    // This method overrides the method in B
    public void p(double i) {
        System.out.println(i);
    }
}
```
Overriding Methods in the Superclass

A subclass inherits methods from a superclass. Sometimes it is necessary for the subclass to modify the implementation of a method defined in the superclass. This is referred to as *method overriding*.

```java
public class Circle extends GeometricObject {

    // Other methods are omitted

    /** Override the toString method defined in GeometricObject */
    public String toString() {
        return super.toString() + "
        raddiis " + radius;
    }
}
```
NOTE

An instance method can be overridden only if it is accessible.

Thus a private method cannot be overridden, because it is not accessible outside its own class.

If a method defined in a subclass is private in its superclass, the two methods are completely unrelated.
The **Object** Class and Its Methods

Every class in Java is descended from the `java.lang.Object` class. If no inheritance is specified when a class is defined, the superclass of the class is `Object`.

```
public class Circle {
    ...
}
```

Equivalent

```
public class Circle extends Object {
    ...
}
```
The `toString()` method in Object

The `toString()` method returns a string representation of the object. The default implementation returns a string consisting of a class name of which the object is an instance, the at sign (`@`), and a number representing this object.

```
Loan loan = new Loan();
System.out.println(loan.toString());
```

The code displays something like `Loan@15037e5`. This message is not very helpful or informative. Usually you should override the `toString` method so that it returns a digestible string representation of the object.
Polymorphism

Polymorphism means that a variable of a supertype can refer to a subtype object.

A class defines a type. A type defined by a subclass is called a *subtype*, and a type defined by its superclass is called a *supertype*. Therefore, you can say that **Circle** is a subtype of **GeometricObject** and **GeometricObject** is a supertype for **Circle**.
Dynamic Binding

Object o is an instance of class $C_1$
$C_1$ is a subclass of $C_2$, $C_2$ is a subclass of $C_3$, ...etc., $C_n$ is the Object class.

If a method in o invokes a method p, the JVM searches the implementation for the method p in $C_1$, $C_2$, ..., $C_{n-1}$ and $C_n$, in this order, until it is found, and that method is invoked.

Since o is an instance of $C_1$, o is also an instance of $C_2$, $C_3$, ..., $C_{n-1}$, and $C_n$
Method Matching vs. Binding

Matching a method signature and binding a method implementation are two issues. The compiler finds a matching method according to parameter type, number of parameters, and order of the parameters at compilation time (overloading)

A method may be implemented in several subclasses. The Java Virtual Machine dynamically binds the implementation of the method at runtime (overriding)
Casting Objects

Casting can be used to convert an object of one class type to another within an inheritance hierarchy. In the code:

```java
Object o = new Student();
works, while
Student b = o;
```

Does not, because a Student object is always an instance of Object, but Object is not in general an instance of Student. For instance, students have grades, but not all objects. If we know that o IS a Student, we can cast o:

```java
Student b = (Student)o;
```
Casting from Superclass to Subclass

Explicit casting must be used when casting an object from a superclass to a subclass. This type of casting may not always succeed.

```java
Apple x = (Apple)fruit;
Orange x = (Orange)fruit;
```
The `instanceof` Operator

Use the `instanceof` operator to test whether an object is an instance of a class:

```java
Object myObject = new Circle();
... // Some lines of code
/** Perform casting if myObject is an instance of Circle */
if (myObject instanceof Circle) {
    System.out.println("The circle diameter is " + ((Circle)myObject).getDiameter());
    ...
}
```
Example: Demonstrating Polymorphism and Casting

This example creates two geometric objects: a circle, and a rectangle, invokes the displayGeometricObject method to display the objects. The displayGeometricObject displays the area and diameter if the object is a circle, and displays area if the object is a rectangle.
The equals Method

The `equals()` method compares the contents of two objects. The default implementation of the `equals` method in the `Object` class is as follows:

```java
public boolean equals(Object obj) {
    return this == obj;
}
```

For example, the `equals` method is overridden in the `Circle` class.

```java
public boolean equals(Object o) {
    if (o instanceof Circle) {
        return radius == ((Circle)o).radius;
    }
    else
        return false;
}
```
NOTE

The == comparison operator is used for comparing two primitive data type values or for determining whether two objects have the same references.

The equals method is intended to test whether two objects have the same contents, provided that the equals method is overridden in the defining class of the objects.
The protected Modifier

- The protected modifier can be applied on data and methods in a class. A protected data or a protected method in a public class can be accessed by any class in the same package or its subclasses, even if the subclasses are in a different package.

- private, default, protected, public
## Accessibility Summary

<table>
<thead>
<tr>
<th>Modifier on members in a class</th>
<th>Accessed from the same class</th>
<th>Accessed from the same package</th>
<th>Accessed from a subclass</th>
<th>Accessed from a different package</th>
</tr>
</thead>
<tbody>
<tr>
<td>public</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>protected</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>–</td>
</tr>
<tr>
<td>default</td>
<td>✔</td>
<td>✔</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>private</td>
<td>✔</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>
Visibility Modifiers

package p1;

public class C1 {
    public int x;
    protected int y;
    int z;
    private int u;
    
    protected void m() {
    }
}

public class C2 {
    C1 o = new C1();
    can access o.x;
    can access o.y;
    can access o.z;
    cannot access o.u;
    
    can invoke o.m();
}

package p2;

public class C3 extends C1 {
     can access x;
     can access y;
     can access z;
     cannot access u;
     
     can invoke m();
}

public class C4 extends C1 {
     extends C1 {
     can access x;
     can access y;
     cannot access z;
     cannot access u;
     
     can invoke m();
}

public class C5 {
    C1 o = new C1();
    can access o.x;
    cannot access o.y;
    cannot access o.z;
    cannot access o.u;
    
    cannot invoke o.m();
}
Modifier hierarchy

We cannot reduce the visibility / accessibility of a method.

For example, if a method is defined as public in the superclass, it must be defined as public in the subclass.
NOTE

The modifiers are used on classes and class members (data and methods), except that the `final` modifier can also be used on local variables in a method. A final local variable is a constant inside a method.
The final Modifier

- The final class cannot be extended:
  ```java
  final class Math {
      ...
  }
  ```

- The final variable is a constant:
  ```java
  final static double PI = 3.14159;
  ```

- The final method cannot be overridden by its subclasses.