CS2030 Lecture 2

Object-Oriented Programming Principles — Inheritance and Polymorphism

Henry Chia (hchia@comp.nus.edu.sg)

Semester 1 2018 / 2019

Lecture Outline

- OO Principles
  - Abstraction
  - Encapsulation
  - Inheritance
    - Super–sub (Parent–child) classes
  - Polymorphism
    - Dynamic vs Static binding
  - Method overloading
  - Mental-modeling objects with inheritance
  - Class variables and methods

A Simplified `Circle` class

- We consider a simplified version of the `Circle` class

```
public class Circle {
    private double radius;

    public Circle(double radius) {
        this.radius = radius;
    }

    public static void main(String[] args) {
        Circle circle = new Circle(1.0);
        System.out.println(circle);
    }
}
```

- What is the output when the above is compiled and run?
- How do we test the `Circle` class without explicitly writing another Java class?

A Simplified `Circle` class

- `jshell` was introduced in Java 9 to provide an interactive shell
  - allows us to enter a command that is immediately executed with result displayed
  - uses REPL to provide an immediate feedback loop

```
$ jshell Circle.java
|  Welcome to JShell -- Version 9.0.4
|  For an introduction type: /help intro

jshell> Circle c = new Circle(1.0)
c ==> Circle@5f341870

jshell> /exit
|  Goodbye
```

Printing the `Circle` class

- Suppose we would like to create a `Circle` object and output in the following format:

```
$ jshell Circle.java
|  Welcome to JShell -- Version 9.0.4
|  For an introduction type: /help intro

jshell> Circle c = new Circle(1.0)
c ==> Circle with area 3.14 and perimeter 6.28

jshell> /exit
|  Goodbye
```

- What are the attributes and methods of the `Circle` class?
- Specifically, you will need to define an *overriding* `toString` method

`Overriding toString` method

- The `toString` method of the `Circle` class can be defined as:

```java
/**
 * Returns a string representation of the Circle, showing its
 * centre coordinates, area and perimeter.
 *
 * @return a string representation of the Circle object.
 */
@Override
public String toString() {
    return "Circle with area " +
        String.format("%.2f", getArea()) + " and perimeter " +
        String.format("%.2f", getPerimeter());
}
```

- The annotation `@Override` indicates to the compiler that the method overrides another one

Overriding `toString` method

- Invoking `javadoc Circle.java` produces the following:

```
public class Circle
extends java.lang.Object
...
public java.lang.String toString()

Returns a string representation of the Circle, showing its centre coordinates,
area and perimeter.

Overrides:
toString in class java.lang.Object

Returns:
a string representation of the Circle object.
```

- This indicates that there is an equivalent `toString` method being overridden in the `java.lang.Object` class from which `Circle` extends (inherits)

`Object`'s `equals` Method

- The other commonly overridden method is the `equals` method
- Within the `Object` class, the `equals` method compares if two object references refer to the same object
- As an example, consider the following

```
jshell> Circle c1 = new Circle(1.0);
c1 ==> Circle with area 3.14 and perimeter 6.28

jshell> Circle c2 = new Circle(1.0);
c2 ==> Circle with area 3.14 and perimeter 6.28

jshell> c1 == c2
$4 ==> false

jshell> c1.equals(c2)
$5 ==> false
```

- If circles of the same radius are deemed equal, then we need to override the `equals` method inherited from `Object`

Overriding `Object`'s `equals` Method

- A naïve way of overriding `equals` method is to include the following method in the `Circle` class

```
@Override
public boolean equals(Object obj) {
    return this.radius == ((Circle) obj).radius;
}
```

- Since the `equals` method takes in a parameter of `Object`
  - **type-cast** `obj` from `Object` type to `Circle` type before accessing the radius in order to check for equality
- But what if the `equals` method of `Circle` was invoked as `(new Circle(1.0)).equals(new Point(0.0, 0.0))`
  - A ClassCastException is thrown

Overriding `Object`'s `equals` Method

- Hence, with a sense of type awareness, the correct way to override the `equals` method is

```
@Override
public boolean equals(Object obj) {
    if (this == obj) {
        return true;
    } else if (obj instanceof Circle) {
        return this.radius ==
            ((Circle) obj).radius;
    } else {
        return false;
    }
}
```

- In essence, first check if it's the same object, then check if it's the same type, then check the associated equality property

Designing a Filled Circle

- Suppose we would like to create a `FilledCircle` object that is a circle filled with a color

```
jshell> /open FilledCircle.java

jshell> new FilledCircle(1.0, Color.BLUE)
$3 ==> Circle with area 3.14, perimeter 6.28
and color java.awt.Color[r=0,g=0,b=255]
```

- Uses the `Color` class provided by Java

```
import java.awt.Color;
```

- What are the different ways in which `FilledCircle` class can be defined?

Design #1: As a Standalone Class

```
import java.awt.Color;

public class FilledCircle {
    private double radius;
    private Color color;

    public FilledCircle(double radius, Color color) {
        this.radius = radius;
        this.color = color;
    }

    public double getArea() {
        return Math.PI * radius * radius;
    }

    public double getPerimeter() {
        return 2 * Math.PI * radius;
    }

    public Color getColor() {
        return color;
    }

    @Override
    public String toString() {
        return "Filled Circle with area " + String.format("%.2f", getArea()) +
            ", perimeter " + String.format("%.2f", getPerimeter()) +
            "\nand color " + getColor();
    }
}
```

Design #2: Using Composition

- **has-a** relationship: `FilledCircle` has a `Circle`

```
public class FilledCircle {
    private Circle circle;
    private Color color;

    public FilledCircle(double radius, Color color) {
        circle = new Circle(radius);
        this.color = color;
    }

    public double getArea() {
        return circle.getArea();
    }

    public double getPerimeter() {
        return circle.getPerimeter();
    }

    public Color getColor() {
        return color;
    }

    @Override
    public String toString() {
        return "Filled Circle with area " + String.format("%.2f", getArea()) +
            ", perimeter " + String.format("%.2f", getPerimeter()) +
            "\nand color " + getColor();
    }
}
```


Design #3: Using Inheritance

- **is-a** relationship: `FilledCircle` is a `Circle`

```
import java.awt.Color;

public class FilledCircle extends Circle {
    private Color color;

    public FilledCircle(double radius, Color color) {
        super(radius);
        this.color = color;
    }

    public Color getColor() {
        return color;
    }

    @Override
    public String toString() {
        return "Filled Circle with area " + String.format("%.2f", getArea()) +
            ", perimeter " + String.format("%.2f", getPerimeter()) +
            "\nand color " + getColor();
    }
}
```

- `Circle` is the parent(super) class, while `FilledCircle` is the child(sub) class

Inheritance

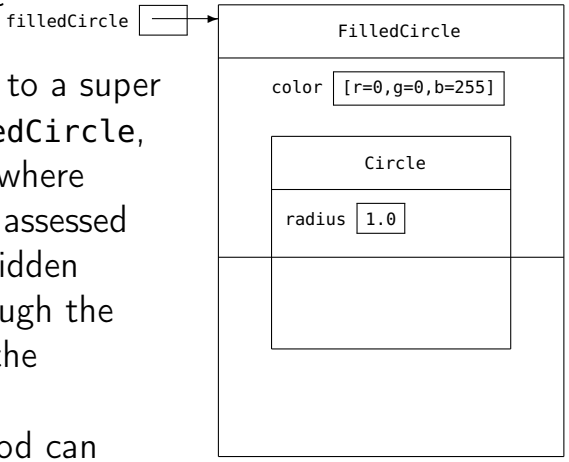
- Notice the child class `FilledCircle` invokes the parent class `Circle`'s constructor using **`super(radius)`** within it's own constructor
- The `radius` variable in `Circle` can also be made accessible to the child class by changing the access modifier

```
public class Circle {
    protected double radius;
    ...
```

- The **`super`** keyword is used for the following purposes:
  - **`super(..)`** to access the parent's constructor
  - **`super.radius`** or **`super.getArea()`** can be used to make reference to the parent's properties or methods; especially useful when there is a conflicting property of the same name in the child class

Modeling Inheritance

- Notice how the child object "wraps-around" the parent
- Type-casting a child object to a super class, e.g. `(Circle) filledCircle`, refers to the parent object where attributes/methods can be assessed
- The only exception is overridden methods; calling them through the parent or child will invoke the overriding methods
- An overridden parent method can only be called within the child class via **`super`**



Inheritance Misuse

- Do not confuse a **has-a** relationship with **is-a**
- Despite that the classes on the left is functional, it does not make sense!

```
public class Point {
    protected double x;
    protected double y;

    public Point(double x, double y) {
        this.x = x;
        this.y = y;
    }

    @Override
    public String toString() {
        return "(" + this.x + ", " + this.y + ")";
    }
}

public class Circle extends Point {
    private double radius;

    public Circle(Point point, double radius) {
        super(point.x, point.y);
        this.radius = radius;
    }

    @Override
    public String toString() {
        return "Circle with radius " + radius +
            " centered at " + super.toString();
    }
}
```


Polymorphism

- How is inheritance useful?
- Other than as an "aggregator" of common code fragments in similar classes, inheritance is used to support **polymorphism**
- Polymorphism means "many forms"

```
jshell> Circle c = new Circle(1.0)
c ==> Circle with area 3.14 and perimeter 6.28

jshell> c = new FilledCircle(1.0, Color.BLUE)
c ==> Filled Circle with area 3.14, perimeter 6.28
and  ... a.awt.Color[r=0,g=0,b=255]

jshell> FilledCircle fc = new FilledCircle(1.0, Color.BLUE)
fc ==> Filled Circle with area 3.14, perimeter 6.28
and  ... a.awt.Color[r=0,g=0,b=255]

jshell> fc = new Circle(1.0)
|  Error:
|  incompatible types: Circle cannot be converted to FilledCircle
|  fc = new Circle(1.0)
|       ^------------^
```


Static binding

- Given an array `Circle[] circles` comprising both `Circle` and `FilledCircle` objects, output these objects one at a time
- In static (or early) binding, we can do something like this:

```
for (Circle circle : circles) {
    if (circle instanceof Circle) {
        System.out.println((Circle) circle);
    } else if (circle instanceof FilledCircle) {
        System.out.println((FilledCircle) circle);
    }
}
```

- Static binding occurs during compile time, i.e. all information needed to call a specific method can be known at compile time

Method Overloading

- Static binding also occurs during method overloading
- Method overloading commonly occurs in constructors

```
public Circle() {
    this.radius = 1.0;
}

public Circle (double radius) {
    this.radius = radius;
}
```

- Whichever method is called is determined during compile time

```
Circle c1 = new Circle();
Circle c2 = new Circle(1.2);
```

- Methods of the same name can co-exist if the *signatures (number, order, and type of arguments)* are different

Dynamic binding

- Contrast static binding with dynamic (or late) binding

```
for (Circle circle : circles) {
    System.out.println(circle);
}
```

- The above will give the same output as in the previous case
- Notice that the exact type of circle, and the exact `toString` method to be overridden, is not known until runtime
- Polymorphism with dynamic binding leads to more easily extensible implementations
  - Simply add a new sub-class of circle that extends the `Circle` class and overriding the appropriate methods
  - Does not require the client code (above) to be modified

Class Variables and Methods

- Having gone through designing a class and allowing objects of that class to be created, how do we keep track of the number objects instantiated at any point of time?
- Clearly, such an aggregate value cannot be stored in every object, since every new instance created would entail that this value be updated in every object
- Use the **`static`** modifier to create class variables and methods

```
public class Circle {
    private double radius;
    private static int numOfCircles = 0;

    public Circle(double radius) {
        this.radius = radius;
        numOfCircles++;
    }

    public static int getNumOfCircles() {
        return numOfCircles;
    }
```


Class Variables and Methods

- Class variables and methods can be called through the class or the object
- Calling through the class is preferred as it makes clear the intent

```
jshell> Circle c = new Circle(1.0)
c ==> Circle with area 3.14 and perimeter 6.28

jshell> FilledCircle fc = new FilledCircle(2.3, Color.BLUE)
fc ==> Filled Circle with area 16.62, perimeter 14.45
an ... a.awt.Color[r=0,g=0,b=255]

jshell> c = new FilledCircle(8.9, Color.WHITE)
c ==> Filled Circle with area 248.85, perimeter 55.92
a ... t.Color[r=255,g=255,b=255]

jshell> Circle.getNumOfCircles()
$7 ==> 3

jshell> c.getNumOfCircles()
$8 ==> 3

jshell> fc.getNumOfCircles()
$9 ==> 3
```


Lecture Summary

- Understand the OO principles of abstraction, encapsulation, inheritance and polymorphism
- Know the difference between static (early) and dynamic (late) binding
- Differentiate between method overloading and method overriding
- Distinguish between an is-a relationship and a has-a relationship and apply the appropriate design
- Extend the mental model of program execution for an object to include inheritance
- Appreciate the use of class variables and methods for aggregation purposes