CS2030 Lecture 3

Inheritance and Polymorphism

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Outline and Learning Outcomes

- Adherence to the abstraction principle using **inheritance**
- Able to construct **super** (parent) and **sub** (child) classes to realize an inheritance relationship
- Able to model an object to include inheritance
- Understand how inheritance can be used to support **polymorphism**
- Distinguish between **method overriding** and **method overloading**
- Appreciate the use of **compile-time type** in static binding and **runtime type** in dynamic binding
- Appreciate the motivation behind the **substitutability** principle

Circle and Filled Circle

- Consider the following `Circle` class with `getArea()` method

```
class Circle {
    private final double radius;

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

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

    public String toString() {
        return "circle with area " + String.format("%.2f", this.getArea());
    }
}
```

- Keeping in mind the *abstraction principle*, implement `FilledCircle` with properties
  - `double radius`
  - `java.awt.Color color`

Sub-Classing with Inheritance

- A child/sub class inherits (extends) from a parent/super class

```
import java.awt.Color;

class FilledCircle extends Circle {
    private final Color color;

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

    public String toString() {
        return "filled " + super.toString() + ", color " + this.color;
    }
}
```

- **super*** keyword can be used within the child class:
  - **super.radius** or **super.toString()** to refer to the parent's properties or calling the parent's methods
  - **super(..)** to access the parent's constructor
  - **super** is not a reference, unlike **this**

`protected` Access Modifier

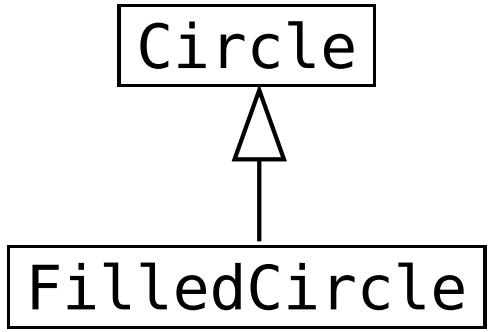
- Where necessary, properties/methods in the super class can be made accessible to a sub-class using the **`protected`** modifier

```
class Circle {
    protected final double radius;

    Circle(double radius) {
        this.radius = radius;
    }
    ...
}
class FilledCircle extends Circle {
    private final Color color;

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

    FilledCircle fillColor(Color color) {
        return new FilledCircle(super.radius, color);
    }
    ...
}
```

- Note that **`protected`** gives access to properties/methods to all other classes (not only sub-classes) *within the same package*

Is-A Relationship

- `FilledCircle` *is a* `Circle`
  - any behaviour of an object of class `T` *can be invoked* from an object of its sub-class `S`
  - e.g. since `FilledCircle` is a `Circle`, `Circle` methods *can be invoked* from `FilledCircle` objects too



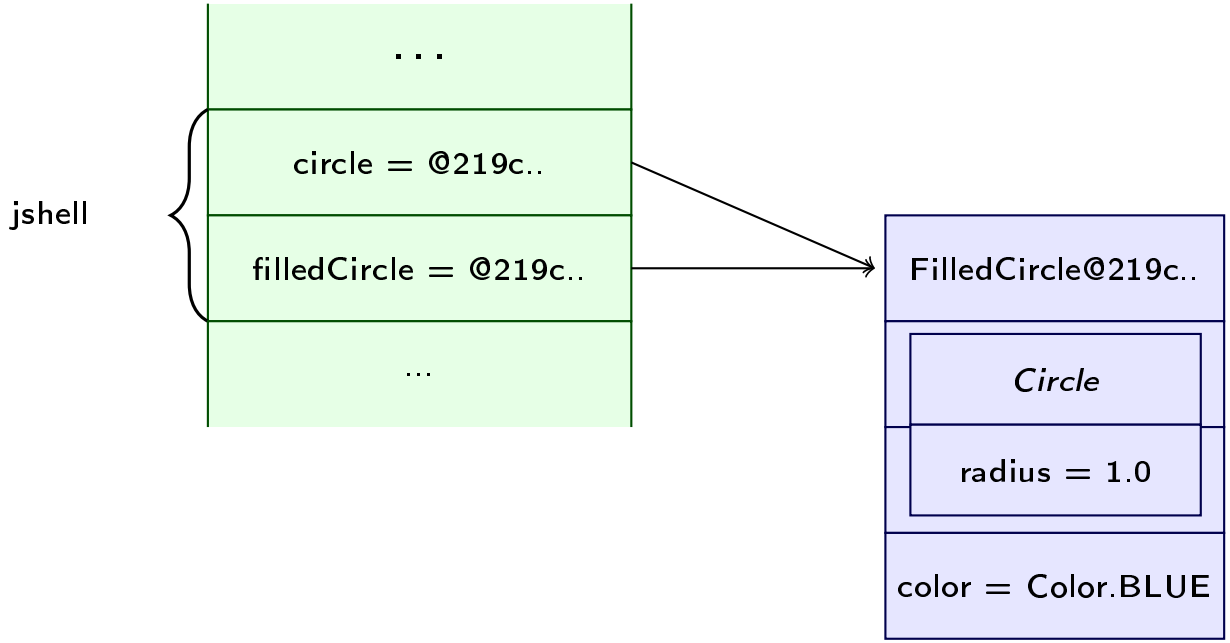

```
jshell> new Circle(1.0)
$.. ==> circle with area 3.14

jshell> new Circle(1.0).getArea()
$.. ==> 3.141592653589793

jshell> new FilledCircle(1.0, Color.BLUE)
$.. ==> filled circle with area 3.14, color java.awt.Color[r=0,g=0,b=255]

jshell> new FilledCircle(1.0, Color.BLUE).getArea()
$.. ==> 3.141592653589793
```

Modeling Inheritance

- Java memory model for the statement

```
jshell> FilledCircle filledCircle = new FilledCircle(1.0, Color.BLUE)
filledCircle ==> filled circle with area 3.14, java.awt.Color[r=0,g=0,b=255]

jshell> Circle circle = filledCircle // to be discussed in the next slide
circle ==> filled circle with area 3.14, java.awt.Color[r=0,g=0,b=255]
```

- Notice how the child object "wraps-around" the parent



Polymorphism

- Poly–morphism means "many forms"
- Consider variable `T t`, referencing an object of class `T`
  - `t` can be assigned with a reference to an object of sub-class `S` with no compilation error

```
jshell> FilledCircle filledCircle = new FilledCircle(1.0, Color.BLUE)
filledCircle ==> filled circle with area 3.14, java.awt.Color[r=0,g=0,b=255]

jshell> Circle circle = new Circle(1.0)
c ==> circle with area 3.14

jshell> circle.getArea()
$.. ==> 3.141592653589793

jshell> circle = filledCircle // circle (type Circle) assigned with reference to FilledCircle
circle ==> filled circle with area 3.14, color java.awt.Color[r=0,g=0,b=255]

jshell> circle.getArea()
$.. ==> 3.141592653589793

jshell> filledCircle.fillColor(Color.GREEN)
$.. ==> filled circle with area 3.14, color java.awt.Color[r=0,g=255,b=0]

jshell> circle.fillColor(Color.GREEN)
|  Error:
|  cannot find symbol
|    symbol:   method fillColor(java.awt.Color)
|  circle.fillColor(Color.GREEN)
|  ^--------------^
```

Polymorphism

- Another example of polymorphism
  - parameter passing, i.e. assignment across methods

```
jshell> void foo(Circle circle) { // Circle or FilledCircle can be passed
   ...>    double area = circle.getArea(); // ok
   ...>    Color color = circle.fillColor(Color.RED); // ??
   ...> }
|  created method foo(Circle), however, it cannot be invoked
|  until method fillColor(java.awt.Color) is declared
```

  - in order to be compilable, `fillColor` is expected to be defined in `Circle` class!
- `Circle` and `FilledCircle` objects can be passed to `foo`
  - `foo` only knows that parameter `circle` would eventually reference "something" that behaves like a `Circle`
  - implementation in the method body must work for `Circle` objects, as well as objects of its sub-classes

Method Overriding

- Defining a method explicitly in a child class that has already been defined in the parent
- A classic example is the `toString()` method
  - all classes inherit from `java.lang.Object`
    - when an expression in JShell evaluates to an object, it invokes the `toString()` method of that object
    - defining a `toString()` method in a sub-class **overrides** the one that is inherited from the parent class
- the `@Override` annotation indicates to the compiler that the method overrides the same one in the parent class
  - useful in ensuring that we are overriding the right method

Overriding `toString` method

- Calling `toString()` from an object

```
jshell> new Circle(1.0)
$.. ==> circle with area 3.14

jshell> new Circle(1.0).toString()
$.. ==> "circle with area 3.14"

jshell> new FilledCircle(1.0, Color.BLUE)
$.. ==> filled circle with area 3.14, color java.awt.Color[r=0,g=0,b=255]

jshell> new FilledCircle(1.0, Color.BLUE).toString()
$.. ==> "filled circle with area 3.14, color java.awt.Color[r=0,g=0,b=255]"
```

- Calling `toString()` from a reference to an object

```
jshell> Circle circle = new Circle(1.0)
c ==> circle with area 3.14

jshell> circle.toString()
$.. ==> "circle with area 3.14"

jshell> circle = new FilledCircle(1.0, Color.BLUE)
c ==> filled circle with area 3.14, color java.awt.Color[r=0,g=0,b=255]

jshell> circle.toString()
$.. ==> "filled circle with area 3.14, color java.awt.Color[r=0,g=0,b=255]"
```

Compile-Time vs Run-Time Type

- Consider the following assignment statement:

```
Circle circle = new FilledCircle(1.0, Color.BLUE);
```

- variable `circle` has a **compile-time type** of `Circle`
  - the type in which the variable is declared
  - restricts the *methods it can call* during compilation, e.g. `getArea()`, `toString()`, but not `fillColor(Color)`
- `circle` has a **run-time type** of `FilledCircle`
  - the type of the object that the variable is referencing when running the program
  - determines the *actual method called* during runtime, e.g. `FilledCircle::toString()`, not `Circle::toString()`

Method Overloading

- Methods of the same name can co-exist if their method *signatures (number, type, order of arguments)* are different
- Consider defining another overloaded `toString(String)` method in the `Circle` class:

```
String toString(String prompt) {
    return prompt + " " + this.toString(); // calls toString()
}
```

```
jshell> Circle circle = new Circle(1.0)
c ==> circle with area 3.14

jshell> circle.toString()
$.. ==> "circle with area 3.14"

jshell> circle.toString("myshell>")
$.. ==> "myshell> circle with area 3.14"

jshell> circle = new FilledCircle(1.0, Color.BLUE)
c ==> filled circle with area 3.14, color java.awt.Color[r=0,g=0,b=255]

jshell> circle.toString()
$.. ==> "filled circle with area 3.14, color java.awt.Color[r=0,g=0,b=255]"

jshell> circle.toString("myshell>")
$.. ==> "myshell> filled circle with area 3.14, color java.awt.Color[r=0,g=0,b=255]"
```

Method Overloading

- Method overloading is very common among constructors within the same class

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

Circle() { // circle with default radius 1.0
    this.radius = 1.0;
}
```

- Use `this(..)` to call one constructor from another

```
Circle() {
    this(1.0);
}
```

- Note that `this(..)` or `super(..)` must be the first statement within the body of the constructor

Static vs Dynamic Binding

- During compilation, *static binding* resolves the method to call (including overloaded methods)
  - in the following `circle.toString()` calls the `toString()` method with no arguments

```
jshell> String foo(Circle circle) {
   ...>     return circle.toString();
   ...> }
|  created method foo(Circle)
```

- During runtime, *dynamic binding* resolves the actual method that is called among all overriding methods
  - since `circle` references an object of type `FilledCircle`, the `toString()` method of `FilledCircle` is invoked

```
jshell> foo(new FilledCircle(1.0, Color.BLUE))
$.. ==> "filled circle with area 3.14, color java.awt.Color[r=0,g=0,b=255]"
```

Substitutability Principle

- If S is a subclass of T (denoted `S <: T`), then an object of type T can be replaced by that of type S *without changing the desirable property* of the program
  - e.g. `FilledCircle` is *substitutable* for `Circle`
    - `Circle circle` referencing a `Circle` can be re-assigned to reference a `FilledCircle` with no compilation error
- *Ponder...* in considering overriding methods:
  - return type of overriding method *cannot be more general* than that of the overridden one
  - accessibility of overriding method *cannot be more restrictive* than the overridden one