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**
- Understand **compile-time type** in static binding and **runtime-type** in dynamic binding
- Appreciate the motivation behind the **substitutability** principle

Circle and Filled Circle

- Given the following `Circle` class with `getArea()` method, implement `FilledCircle` class with radius and color

```
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());
    }
}
```

- **Abstraction Principle**: *Each significant piece of functionality in a program should be implemented in just one place in the source code. Where similar functions are carried out by distinct pieces of code, it is generally beneficial to combine them into one by abstracting out the varying parts.* — *Benjamin C. Pierce*

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
  - unlike **this**, **super** is not a reference

`protected` Access Modifier

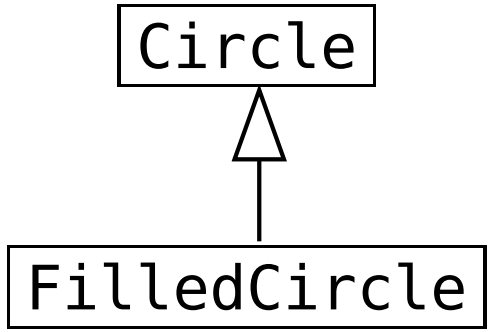
- Where necessary, properties/methods in the super class can be made accessible to a sub-class using the **`protected`** modifier

```
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*

Inheritance: 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
```

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`
  - defining a `toString()` method in a sub-class **overrides** the one that is inherited from the parent class
    - when an expression in JShell evaluates to an object, it invokes the `toString()` method of that object
- 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]"
```

- What about calling `toString()` via 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) // we can do this??
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:

Compile-time type

Run-time type

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

- variable `circle` has a **compile-time type** of `Circle`
  - the type of the variable declared
  - restricts the *methods it can call during compilation*
    - e.g. `getArea()`, `toString()`, but not `fillColor(Color)`

Can call doesn't mean it's the result called!!!

E,g, it cannot call FilledCircle getColor() method, but can call Circle toString() method HOWEVER, since filledCircle @override the toString method, the toString will print out FilledCircle string method

- `circle` has a **run-time type** of `FilledCircle`
  - the type of the object that the variable is referencing
  - determines the *actual method called during runtime*
    - e.g. `FilledCircle::toString()`, not `Circle::toString()`

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 object
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) // compile-time type decide whether method can be called
|  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); // ??
   ...>    System.out.println(circle); // or System.out.println(circle.toString());
   ...> }
|  created method foo(Circle), however, it cannot be invoked
|  until method fillColor(java.awt.Color) is declared
```

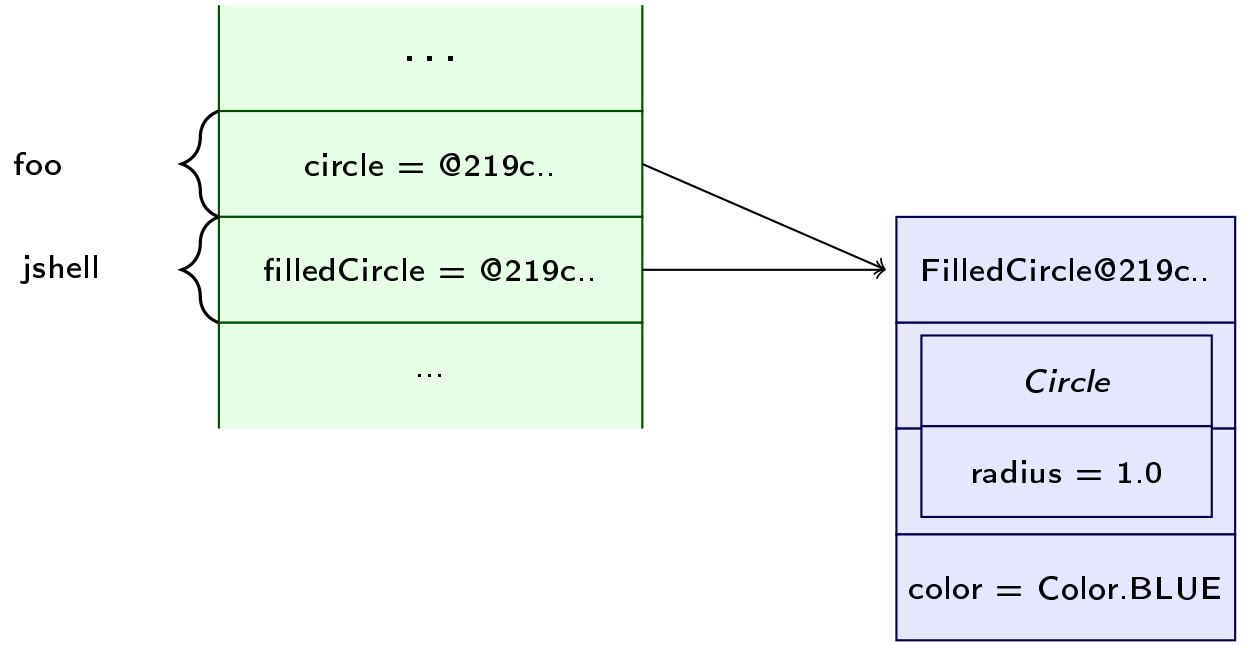
  - in order to be compilable, `fillColor` is expected to be defined in `Circle` class!

- `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

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> foo(filledCircle)
filled circle with area 3.14, color java.awt.Color[r=0,g=0,b=255]
```



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

Method Overloading

- Methods of the same name can co-exist if their method *signatures (number, type, order of arguments)* are different
  - e.g. defining an overloaded method `toString(String)` in 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]"
```

  - What if `toString(String)` defined in `FilledCircle` instead?

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> ImList<Circle> circles = new ImList<Circle>().
   ...> add(new Circle(1.0)).
   ...> add(new FilledCircle(1.0, Color.BLUE))
circles ==> [circle with area 3.14, circle with area 3.14, java.awt.Color[r=0,g=0,b=255]]

jshell> for (Circle circle : circles) {
   ...>     System.out.println(circle); // or System.out.println(circle.toString())
   ...> }
circle with area 3.14
circle with area 3.14, java.awt.Color[r=0,g=0,b=255]
```

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

Substitutability Principle

- If S is a subclass of 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