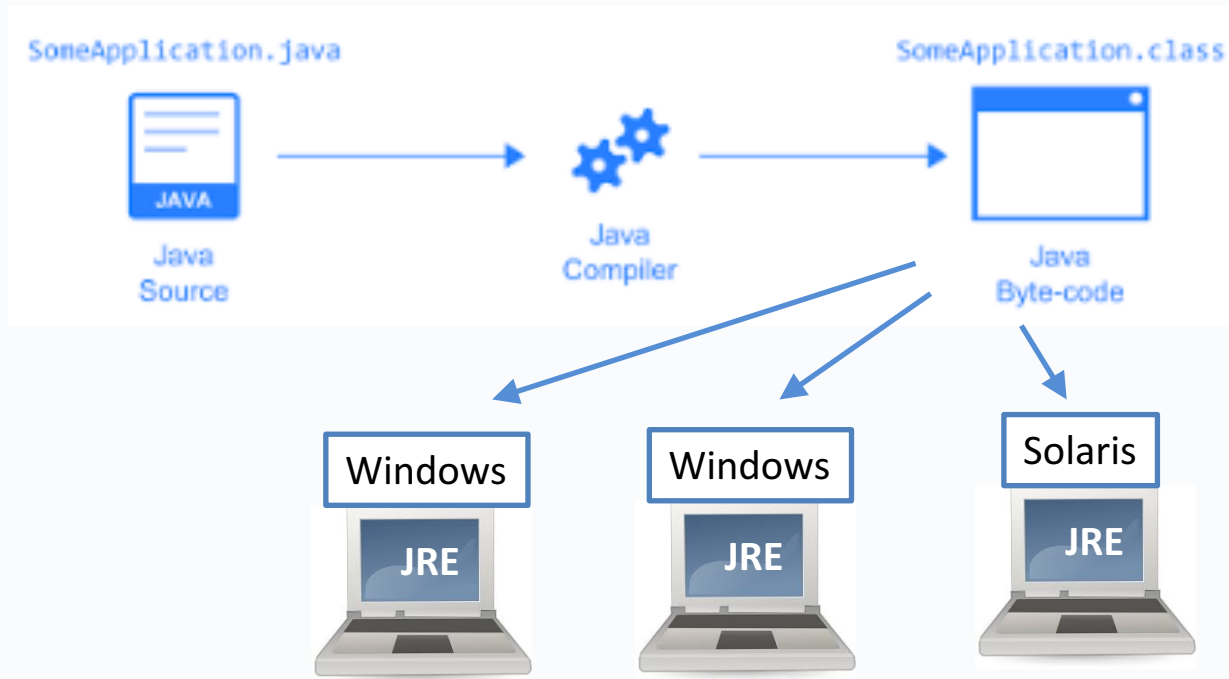


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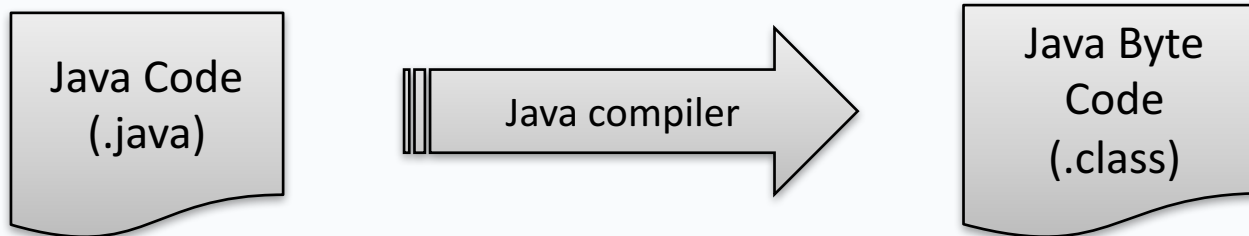
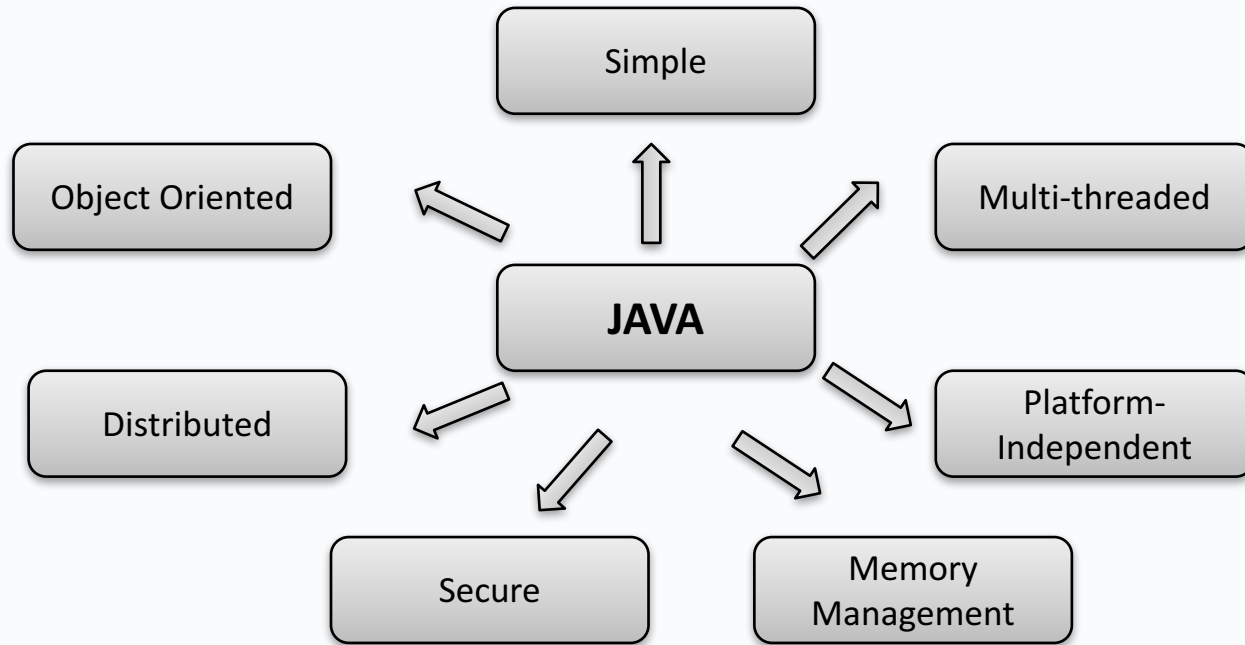
Object Oriented Programming (OOP) in Java

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OOP in Java

- ❖ Object Oriented Programming (OOP)
- ❖ Inheritance in OOP
- ❖ Introduction to Classes and Objects
- ❖ Subclasses and Inheritance
- ❖ Abstract Classes
- ❖ Single Inheritance versus Multiple Inheritance
- ❖ Interfaces
- ❖ Method Forwarding (Has-a relationship)
- ❖ Method Overriding (Polymorphism)
- ❖ Method Overloading
- ❖ Constructors

Object Oriented Programming (OOP)

In procedural programming languages (like 'C'), programming tends to be **action-oriented**, whereas in Java - programming is **object-oriented**.

In **procedural** programming,

- groups of actions that perform some task are formed into functions and functions are grouped to form programs.

In **OOP**,

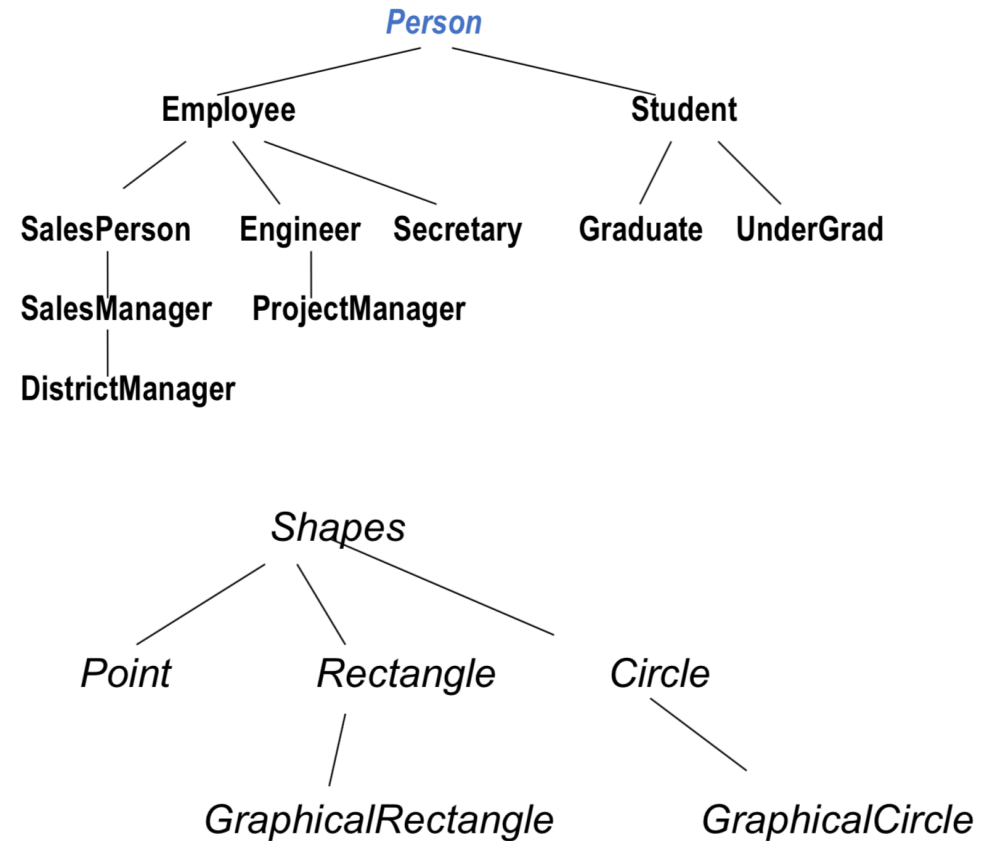
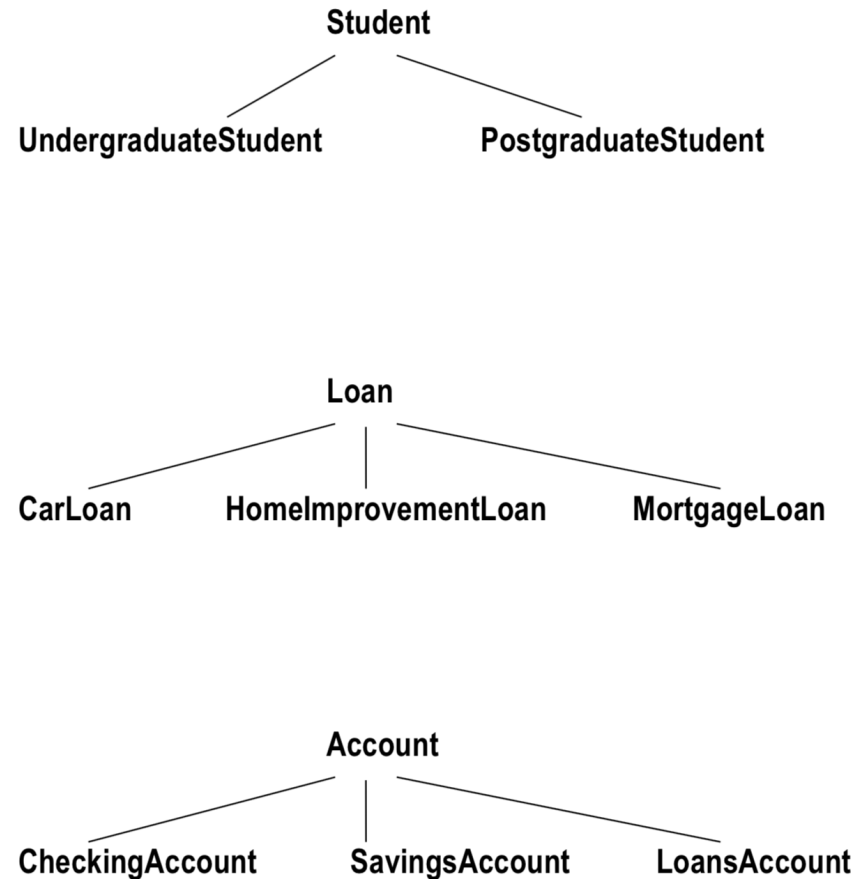
- programmers concentrate on creating their own user-defined types called **classes**.
- each **class** contains **data** as well as the set of **methods** (procedures) that manipulate the data.
- an instance of a user-defined type (i.e. a **class**) is called an **object**.
- OOP **encapsulates** data (attributes) and methods (behaviours) into **objects**, the data and methods of an object are intimately tied together.
- Objects have the property of *information hiding*.

Inheritance in Object Oriented Programming (OOP)

- ❖ **Inheritance** is a form of software reusability in which new classes are created from the existing classes by absorbing their attributes and behaviours.
- ❖ Instead of defining completely (separate) new class, the programmer can designate that the new class is to **inherit** attributes and behaviours of the existing class (called **superclass**). The new class is referred to as **subclass**.
- ❖ Programmer can **add more attributes and behaviours** to the *subclass*, hence, normally **subclasses** have **more features** than their *super classes*.

Inheritance in Object Oriented Programming (OOP)

Inheritance relationships form tree-like hierarchical structures. For example,



“*is-a*” - Inheritance relationship

- ❖ In an “**is-a**” relationship, an object of a subclass may also be treated as an object of the superclass.
- ❖ For example, *UndergraduateStudent* can be treated as *Student* too.
- ❖ You should use *inheritance* to model “is-a” relationship.

Very Important:

- ❖ Don’t use inheritance unless **all or most** inherited attributes and methods **make sense**.
- ❖ For example, mathematically a *circle* is-a (an) *oval*, however you should **not** inherit a class *circle* from a class *oval*. A class *oval* can have one method to set *width* and another to set *height*.

“Has-a” - Association relationship

- ❖ In a “has-a” relationship, a **class object has an object of another class** to store its state or do its work, i.e. it “has-a” reference to that other object.
- ❖ For example, a Rectangle Is-NOT-a Line.
However, we may use a Line to draw a Rectangle.
- ❖ The “has-a” relationship is quite different from an “is-a” relationship.
- ❖ “Has-a” relationships are examples of creating new classes by *composition* of existing classes (as oppose to *extending* classes).

Very Important:

- ❖ Getting “Is-a” versus “Has-a” relationships correct is both *subtle* and potentially *critical*. You should *consider* all *possible* future *usages* of the classes before finalising the hierarchy.
- ❖ It is possible that *obvious solutions may not work* for some applications.

Designing a Class

- Think carefully about the functionality (methods) a class should offer.
- Always **try to keep data private** (local).
- Consider **different ways** an object may be **created**.
- Creating an object may require different actions such as initializations.
- Always initialize data.
- If the object is no longer in use, free up all the associated resources.
- **Break up** classes with **too many responsibilities**.
- In OO, classes are often closely related. “**Factor out**” common attributes and behaviours and place these in a class. Then use suitable relationships between classes (for example, “is-a” or “has-a”).

Introduction to Classes and Objects

- ❖ A class is a collection of **data** and **methods** (procedures) that operate on that data.
- ❖ For example,
a **circle** can be described by the **x, y position** of its centre and by its **radius**.
- ❖ We can define some useful methods (procedures) for circles,
compute **circumference**, compute area, check whether points are inside the circle,
etc.
- ❖ By defining the **Circle class** (as below), we can create a **new data type**.

The class Circle

- ❖ For simplicity, the methods for *getter* and *setters* are not shown in the code.

```
public class Circle {  
  
    protected static final double pi = 3.14159;  
    protected int x, y;  
    protected int r;  
  
    // Very simple constructor  
    public Circle(){  
        this.x = 1;  
        this.y = 1;  
        this.r = 1;  
    }  
    // Another simple constructor  
    public Circle(int x, int y, int r){  
        this.x = x;  
        this.y = y;  
        this.r = r;  
    }  
  
    /**  
     * Below, methods that return the circumference  
     * area of the circle  
     */  
    public double circumference( ) {  
        return 2 * pi * r ;  
    }  
    public double area ( ) {  
        return pi * r * r ;  
    }  
}
```

Objects are Instances of a class

In Java, objects are created by instantiating a class.

For example,

```
Circle c ;  
c = new Circle ( ) ;
```

OR

```
Circle c = new Circle ( ) ;
```

Accessing Object Data

We can access data fields of an object.

For example,

```
Circle c = new Circle ( ) ;
```

```
// Initialize our circle to have centre (2, 5)
```

```
// and radius 1.
```

```
// Assuming, x, y and r are not private
```

```
c.x = 2;
```

```
c.y = 5;
```

```
c.r = 1;
```

Using Object Methods

To access the methods of an object, we can use the same syntax as accessing the data of an object:

```
Circle c = new Circle ( ) ;  
double a;
```

```
c.r = 2;           // assuming r is not private
```

```
a = c.area( );
```

```
//Note that its not :    a = area(c) ;
```

Subclasses and Inheritance:

First Approach

We want to implement *GraphicalCircle*.

This can be achieved in at least 3 different ways.

First Approach:

- ❖ In this approach we are creating the **new separate class** for *GraphicalCircle* and **re-writing** the code already available in the class *Circle*.
- ❖ For example, we re-write the methods *area* and *circumference*.
- ❖ Hence, this approach is NOT elegant, in fact its the **worst** possible solution.
Note again, its the **worst** possible solution!

```
// The class of graphical circles

public class GraphicalCircle {
    int x, y;
    int r;
    Color outline, fill;

    public double circumference( ) {
        return 2 * 3.14159 * r ;
    }
    public double area ( ) {
        return 3.14159 * r * r ;
    }

    public void draw(Graphics g) {
        g.setColor(outline);
        g.drawOval(x-r, y-r, 2*r, 2*r);
        g.setColor(fill);
        g.fillOval(x-r, y-r, 2*r, 2*r);
    }
}
```

Subclasses and Inheritance: *Second Approach*

- ❖ We want to implement *GraphicalCircle* so that it can make use of the code in the class *Circle*.
- ❖ This approach uses “**has-a**” relationship.
- ❖ That means, a *GraphicalCircle* has a (mathematical) *Circle*.
- ❖ It uses methods from the class *Circle* (*area* and *circumference*) to define some of the new methods.
- ❖ This technique is also known as **method forwarding**.

```
public class GraphicalCircle2 {  
    // here's the math circle  
    Circle c;  
    // The new graphics variables go here  
    Color outline, fill;  
  
    // Very simple constructor  
    public GraphicalCircle2() {  
        c = new Circle();  
        this.outline = Color.black;  
        this.fill = Color.white;  
    }  
  
    // Another simple constructor  
    public GraphicalCircle2(int x, int y, int r,  
                             Color o, Color f) {  
        c = new Circle(x, y, r);  
        this.outline = o;  
        this.fill = f;  
    }  
  
    // draw method , using object 'c'  
    public void draw(Graphics g) {  
        g.setColor(outline);  
        g.drawOval(c.x - c.r, c.y - c.r, 2 * c.r, 2 * c.r);  
        g.setColor(fill);  
        g.fillOval(c.x - c.r, c.y - c.r, 2 * c.r, 2 * c.r);  
    }  
}
```

Subclasses and Inheritance:

Third Approach - Extending a Class

- ❖ We can say that *GraphicalCircle* **is-a** *Circle*.
- ❖ Hence, we can define *GraphicalCircle* as an **extension**, or *subclass* of *Circle*.
- ❖ The subclass *GraphicalCircle* **inherits** all the variables and methods of its superclass *Circle*.

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

public class GraphicalCircle extends Circle {

    Color outline, fill;
    public GraphicalCircle(){
        super();
        this.outline = Color.black;
        this.fill = Color.white;
    }
    // Another simple constructor
    public GraphicalCircle(int x, int y,
                           int r, Color o, Color f){
        super(x, y, r);
        this.outline = o; this.fill = f;
    }

    public void draw(Graphics g) {
        g.setColor(outline);
        g.drawOval(x-r, y-r, 2*r, 2*r);
        g.setColor(fill);
        g.fillOval(x-r, y-r, 2*r, 2*r);
    }
}
```

Subclasses and Inheritance: Example

We can assign an instance of *GraphicCircle* to a *Circle* variable. For example,

```
GraphicCircle gc = new GraphicCircle();  
...  
double area = gc.area();  
...  
Circle c = gc;  
// we cannot call draw method for "c".
```

Important:

- ❖ Considering the variable "c" is of type *Circle*,
- ❖ we can only access attributes and methods available in the class *Circle*.
- ❖ we **cannot** call *draw* method for "c".

Super classes, Objects, and the Class Hierarchy

- ❖ Every class has a superclass.
- ❖ If we don't define the superclass, by default, the superclass is the class **Object**.

Object Class :

- ❖ Its the only class that does not have a superclass.
- ❖ The methods defined by **Object** can be called by any Java object (instance).
- ❖ Often we need to **override** the following methods:
 - **toString()**
 - read the API at [https://docs.oracle.com/en/java/javase/11/docs/api/java.base/java/lang/Object.html#toString\(\)](https://docs.oracle.com/en/java/javase/11/docs/api/java.base/java/lang/Object.html#toString())
 - **equals()**
 - read the API at [https://docs.oracle.com/en/java/javase/11/docs/api/java.base/java/lang/Object.html#equals\(java.lang.Object\)](https://docs.oracle.com/en/java/javase/11/docs/api/java.base/java/lang/Object.html#equals(java.lang.Object))
 - **hashCode()**

Abstract Classes

Using **abstract** classes,

- ❖ we can declare classes that define **only** part of an implementation,
- ❖ leaving extended classes to provide specific implementation of some or all the methods.

The benefit of an **abstract** class

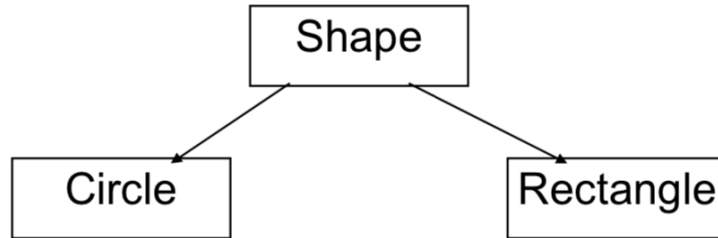
- ❖ is that methods may be declared such that the programmer knows **the interface definition** of an object,
- ❖ however, methods can be **implemented differently** in different subclasses of the abstract class.

Abstract Classes

Some rules about abstract classes:

- ❖ An abstract class is a class that is **declared abstract**.
- ❖ If a class **includes abstract methods**, then the class itself must be declared abstract.
- ❖ An abstract class **cannot be instantiated**.
- ❖ A subclass of an abstract class can be instantiated if it overrides each of the abstract methods of its superclass and provides **an implementation** for **all** of them.
- ❖ If a subclass of an abstract class **does not implement** all the abstract methods it inherits, that subclass is itself abstract.

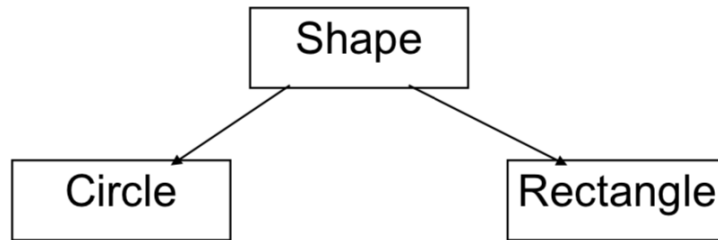
Abstract Class: Example



```
public abstract class Shape {  
  
    public abstract double area();  
    public abstract double circumference();  
  
}
```

```
public class Circle extends Shape {  
  
    protected static final double pi = 3.14159;  
    protected int x, y;  
    protected int r;  
  
    // Very simple constructor  
    public Circle(){  
        this.x = 1;  
        this.y = 1;  
        this.r = 1;  
    }  
    // Another simple constructor  
    public Circle(int x, int y, int r){  
        this.x = x;  
        this.y = y;  
        this.r = r;  
    }  
  
    /**  
     * Below, methods that return the circumference  
     * area of the circle  
     */  
    public double circumference( ) {  
        return 2 * pi * r ;  
    }  
    public double area ( ) {  
        return pi * r * r ;  
    }  
  
}
```

Abstract Class: Example



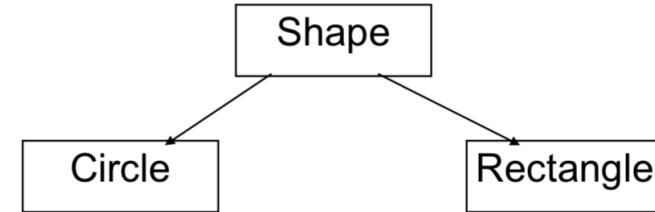
```
public abstract class Shape {  
    public abstract double area();  
    public abstract double circumference();  
}
```

```
public class Rectangle extends Shape {  
    protected double width, height;  
  
    public Rectangle() {  
        width = 1.0;  
        height = 1.0;  
    }  
  
    public Rectangle(double w, double h) {  
        this.width = w;  
        this.height = h;  
    }  
  
    public double area(){  
        return width*height;  
    }  
  
    public double circumference() {  
        return 2*(width + height);  
    }  
}
```

Abstract Class: Example

Some points to note:

- ❖ As **Shape** is an abstract class, we cannot instantiate it.
- ❖ Instantiations of **Circle** and **Rectangle** can be assigned to variables of **Shape**.
No cast is necessary
- ❖ In other words, subclasses of **Shape** can be assigned to elements of an array of **Shape**.
No cast is necessary.
- ❖ We can invoke **area()** and **circumference()** methods for **Shape** objects.



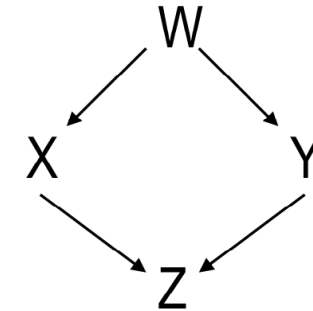
We can now write code like this:

```
// create an array to hold shapes
Shape[] shapes = new Shape[4];
shapes[0] = new Circle(4, 6, 2);
shapes[1] = new Rectangle(1.0, 3.0);
shapes[2] = new Rectangle(4.0, 2.0);
shapes[3] = new GraphicalCircle(1, 1, 6,
                                Color.green, Color.yellow);

double total_area = 0;
for(int i = 0; i < shapes.length; i++) {
    // compute the area of the shapes
    total_area += shapes[i].area();
}
```

Single Inheritance versus Multiple Inheritance

- In Java, a new class can extend exactly one superclass - a model known as *single inheritance*.
- Some object-oriented languages employ *multiple inheritance*, where a new class can have two or more *super classes*.
- In multiple inheritance, **problems** arise when a superclass's behaviour is *inherited in two/multiple ways*.
- Single inheritance precludes some useful and correct designs.
- In Java, **interface** in the class hierarchy can be used to add multiple inheritance, more discussions on this later.

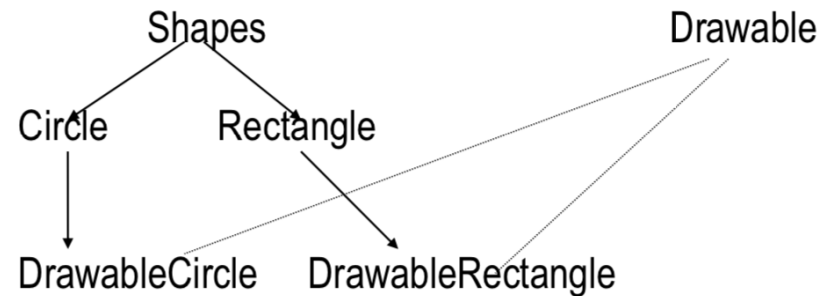


Diamond inheritance
problem

Interfaces in Java

- ❖ Interfaces are like abstract classes, but with few **important differences**.
- ❖ All the methods defined within an interface are **implicitly abstract**. (We don't need to use abstract keyword, however, to improve clarity one can use abstract keyword).
- ❖ **Variables** declared in an interface must be **static and final**, that means, they must be **constants**.
- ❖ Just like a class **extends** its superclass, it also can optionally **implements** an interface.
- ❖ In order to implement an interface, a class must first declare the interface in an **implements** clause, and then it must provide an implementation for all of the abstract methods of the interface.
- ❖ A class can “**implements**” **more** than one **interfaces**.
- ❖ More discussions on “**interfaces**” later in the course.

Interfaces in Java: Example



```
public interface Drawable {
    public void setColor(Color c);
    public void setPosition(double x, double y);
    public void draw(Graphics g);
}

public class DrawableRectangle
    extends Rectangle
    implements Drawable {

    private Color c;
    private double x, y;

    .....

    // Here are implementations of the
    // methods in Drawable
    // we also inherit all public methods
    // of Rectangle

    public void setColor(Color c) { this.c = c; }
    public void setPosition(double x, double y) {
        this.x = x; this.y = y; }
    public void draw(Graphics g) {
        g.drawRect(x, y, w, h, c); }
}
```

Using Interfaces: Example

- ❖ When a class **implements** an interface, instance of that class can also be **assigned to** variables of the **interface type**.

```
Shape[] shapes = new Shape[3];
Drawable[] drawables = new Drawable[3];

DrawableCircle dc = new DrawableCircle(1.1);
DrawableSquare ds = new DrawableSquare(2.5);
DrawableRectangle dr = new DrawableRectangle(2.3,
4.5);

// The shapes can be assigned to both arrays
shapes[0] = dc; drawables[0] = dc;
shapes[1] = ds; drawables[1] = ds;
shapes[2] = dr; drawables[2] = dr;

// We can invoke abstract method
// in Drawable and Shapes

double total_area = 0;
for(int i=0; i< shapes.length; i++) {

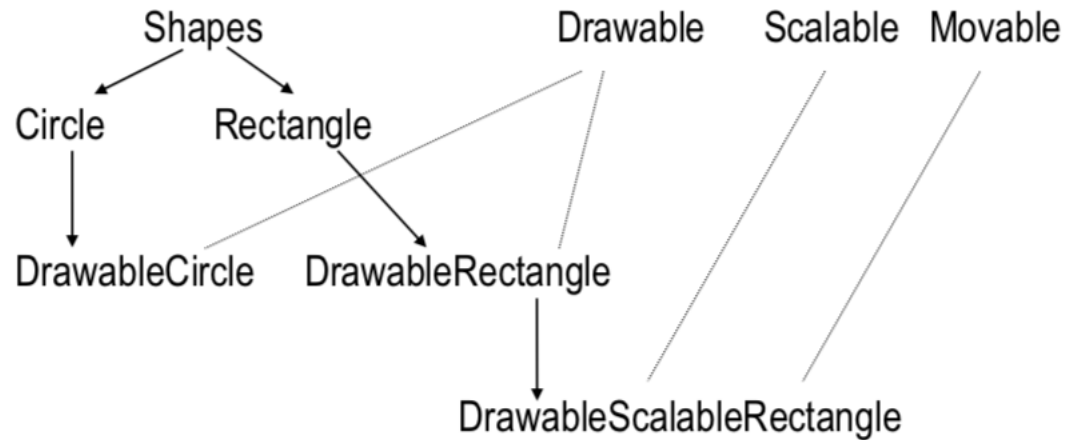
    total_area += shapes[i].area();

    drawables[i].setPosition(i*10.0, i*10.0);

    // assume that graphic area 'g' is
    // defined somewhere
    drawables[i].draw(g);
}
```

Implementing Multiple Interfaces

A class can **implements** more than one interfaces. For example,



```
public class DrawableScalableRectangle
    extends DrawableRectangle
    implements Movable, Scalable {

    // methods go here ....

}
```

Extending Interfaces

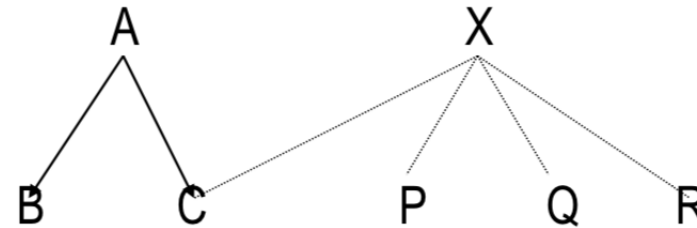
- ❖ Interfaces can have **sub-interfaces**, just like classes can have subclasses.
- ❖ A sub-interface **inherits all** the abstract methods and constants of its super-interface, and may define new abstract methods and constants.
- ❖ Interfaces **can extend** more than one interface at a time. For example,

```
public interface Transformable
    extends Scalable, Rotable, Reflectable {}

public interface DrawingObject
    extends Drawable, Transformable{}

public class Shape implements DrawingObject {
    ... }
```

Method Forwarding



- ❖ Suppose class C extends class A, and also implements interface X.
- ❖ As all the methods defined in interface X are abstract, class C needs to implement all these methods.
- ❖ However, there are three implementations of X (in P,Q,R).
- ❖ In class C, we may want to use one of these implementations, that means, we may want to use some or all methods implemented in P, Q or R.
- ❖ Say, we want to use methods implemented in P. We can do this by creating an object of type class P in class C, and through this object access all the methods implemented in P.
- ❖ Note that, in class C, we do need to provide required stubs for all the methods in the interface X. In the body of the methods we may simply call methods of class P via the object of class P.
- ❖ This approach is also known as **method forwarding**.

Methods Overriding (Polymorphism)

- ❖ When a class defines a method using the **same** name, return type, and by the number, type, and position of its arguments as a method in its *superclass*, the method in the class **overrides** the method in the *superclass*.
- ❖ If a method is invoked for an object of the class, it's the **new definition** of the method that is called, and **not** the superclass's **old definition**.

Polymorphism

- An object's ability to decide what method to apply to itself, depending on where it is in the inheritance hierarchy, is usually called *polymorphism*.

Methods Overriding: Example

In the example below,

- ❖ if **p** is an instance of class **B**,
p.f() refers to **f()** in class **B**.
- ❖ However, if **p** is an instance of class **A**,
p.f() refers to **f()** in class **A**.

The example also shows how to refer to the **overridden** method using **super** keyword.

```
class A {  
    int i = 1;  
    int f() { return i;}  
}  
  
class B extends A {  
    int i;                                // shadows i from A  
    int f() {                             // overrides f() from A  
        i = super.i + 1;                 // retrives i from A  
        return super.f() + i;           // invokes f() from A  
    }  
}
```

Methods Overriding: Example

Suppose class C is a subclass of class B, and class B is a subclass of class A.

Class A and class C both define method `f()`.

From class C, we can refer to the overridden method by,

`super.f()`

This is because class B inherits method `f()` from class A.

However,

- ❖ if **all the three** classes define `f()`, then calling `super.f()` in class C invokes class B's definition of the method.
- ❖ **Importantly**, in this case, there is **no way** to invoke `A.f()` from within class C.
- ❖ Note that `super.super.f()` is **NOT legal** Java syntax.

Method Overloading

Defining methods with the **same name** and **different** argument or return types is called *method overloading*.

In Java,

- ❖ a method is distinguished by its **method signature** - its name, return type, and by the number, type, and position of its arguments

For example,

```
double add(int, int)
double add(int, double)
double add(float, int)
double add(int, int, int)
double add(int, double, int)
```

Data Hiding and Encapsulation

We can **hide** the **data** within the class and make it available only through the methods.

This can help in maintaining the consistency of the data for an object, that means the state of an object.

Visibility Modifiers

Java provides five access modifiers (for variables/methods/classes),

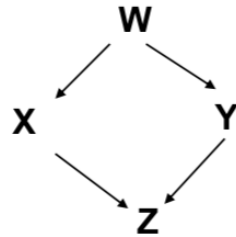
- ❖ **public** - visible to the world
- ❖ **private** - visible to the class only
- ❖ **protected** - visible to the package and all subclasses
- ❖ **No modifier (default)** - visible to the package

Constructors

- ❖ Good practice to **define** the required constructors for **all** classes.
- ❖ If a constructor is **not defined** in a class,
 - **no-argument** constructor is **implicitly inserted**.
 - this no-argument constructor invokes the **superclass's no-argument** constructor.
 - if the parent class (superclass) doesn't have a visible constructor with no-argument, it results in a compilation **error**.
- ❖ If the **first statement** in a constructor is **not** a call to **super()** or **this()**, a call to **super ()** is **implicitly** inserted.
- ❖ If a constructor is **defined** with **one or more arguments**, **no-argument** constructor is **not inserted** in that class.
- ❖ A class can have **multiple** constructors, with **different signatures**.
- ❖ The word “**this**” can be used to call another constructor in the same class.

Diamond Inheritance Problem: A Possible Solution

Using **multiple inheritance** (in C++):

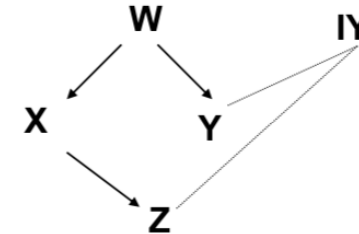


we achieve the following:

- In class Z, we can use methods and variables defined in X, W **and** Y.
- Objects of classes Z and Y can be assigned to variables of **type Y**.
- and more ...

Using **single inheritance** in Java:

```
class W { }  
interface IY { }  
class X extends W { }  
class Y extends W implements IY { }  
class Z extends X implements IY { }
```



we achieve the following:

- In class Z, we can use methods and variables defined in X and W. In class Z, if we want to use methods implemented in class Y, we can use **method forwarding** technique. That means, in class Z, we can create an object of type class Y, and via this object we can access (in class Z) all the methods defined in class Y.
- Objects of classes Z and Y can be assigned to variables of **type IY** (instead of Y).
- and more

Some References to Java Tutorials

- ❖ <https://docs.oracle.com/javase/tutorial/>
- ❖ <https://www.w3schools.com/java/default.asp>
- ❖ <https://www.tutorialspoint.com/java/index.htm>