

MAHARISHI UNIVERSITY of MANAGEMENT

Engaging the Managing Intelligence of Nature

Computer Science Department

CS390 Foundamental Programming

Practices (FPP)

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Lecture 4: Inheritance, Interfaces, and Polymorphism

Wholeness of the Lesson

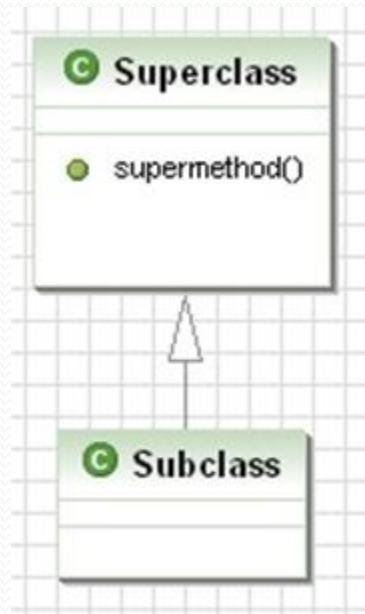
Java supports inheritance between classes in support of the OO concepts of inherited types and polymorphism. Interfaces support encapsulation, play a role similar to abstract classes, and provide a safe alternative to multiple inheritance. Likewise, relationships of any kind that are grounded on the deeper values at the source of the individuals involved result in fuller creativity of expression with fewer mistakes.

Outline of Topics

- **Introduction to Inheritance – Example of Subclassing a Class**
- The "IS-A" and LSP Criteria for Proper Use of Inheritance
- Rules for Subclass Constructors
- Inheritance and the Object Class
- Inheritance for Generalization and Introduction to Polymorphism
- Order of Execution with Inheritance
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Introduction to Inheritance

- *Definition.* A class Subclass *inherits from* another class Superclass if objects of type Subclass have automatic access to the "**available**" methods and variables that have been defined in class Superclass. By "automatic access" we mean that no explicit instantiation of (or reference to) the class Superclass is necessary in order for objects of type Subclass to be able to call methods defined in class Superclass. By "available" methods and variables, we mean methods and variables that have been declared either *public* or *protected* (or have *package level access* if in the same package).



```
class Superclass {  
    protected void supermethod() {  
        int x = 0;  
    }  
}  
  
class Subclass extends Superclass {  
}  
  
class Main {  
    public static void main(String[] args) {  
        Subclass sub = new Subclass();  
        sub.supermethod();  
    }  
}
```

A class, method, or variable labeled *protected* is **accessible** to all *subclasses*.

The protected Keyword

- Methods and variables in a class that are qualified with the **protected** access specifier are accessible to *all subclasses* of the class and *all classes in the same package* as the class. Therefore, the access specifiers in Java, listed from most to least restrictive, are:

`private, <package level>, protected, public`

- Most feel that it is a best practice to make all instance variables in a class *private* – just giving **protected** access is considered a violation of encapsulation.
- Warning! The rules governing the use of the **protected** keyword are somewhat more involved than this – these will be discussed at the end of the lesson.

Motivation for Inheritance

- In our programming projects, we may find that we define two classes that have many of the same fields and methods. It is natural to think of a single class that generalizes the two classes and that contains the code needed by both.

Secretary
properties:

name
address
telNum
vehicleType
numYears

behavior:

computeSalary()

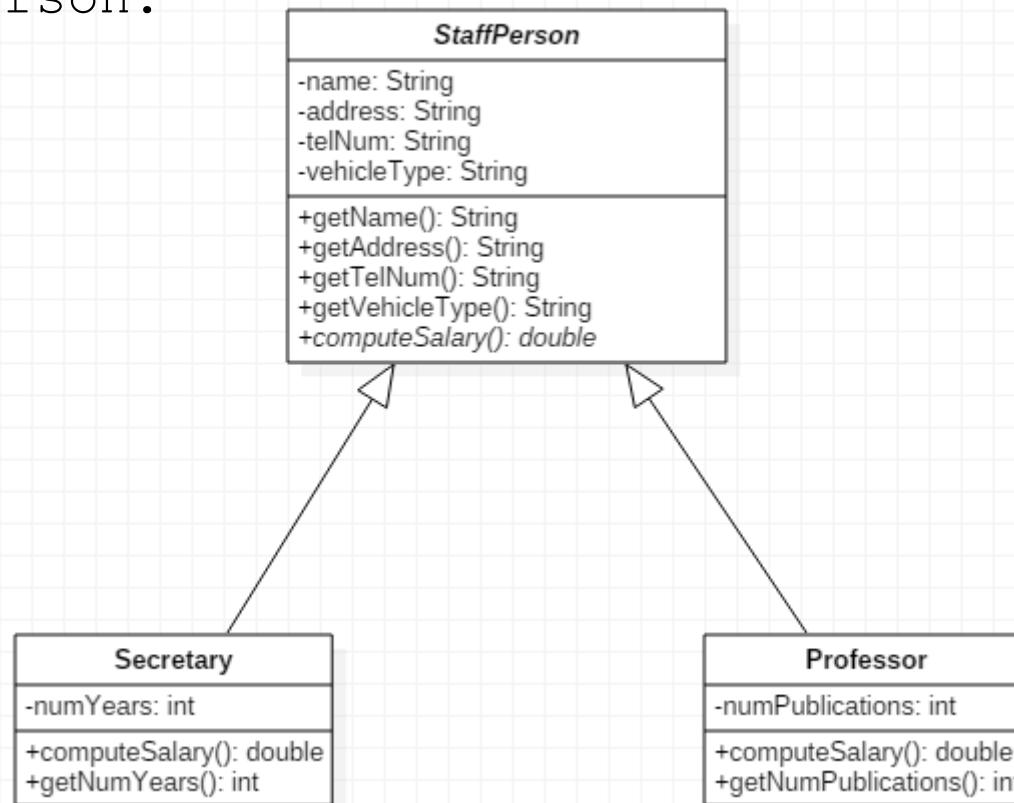
Professor
properties:

name
address
telNum
vehicleType
numPublications

behavior:

computeSalary()

Strategy: Create a *generalization* of Secretary and Professor from which both of these classes *inherit*. A StaffPerson class can be defined having nearly all fields that were previously in Secretary and Professor. We then require Secretary and Professor to inherit from StaffPerson.



When the classes have this relationship, we may view the type of an instance of a subclass as being that of the superclass. For example, we can instantiate like this:

```
StaffPerson person1 = new Professor();  
StaffPerson person2 = new Secretary();
```

This is similar in spirit to the automatic conversions that are done for primitive types:

```
byte b = 8;  
int k = b;
```

Another Example of Inheritance: Manager as a subclass of Employee

```
//Employee class, as defined in previous lessons
class Employee {
    Employee(String aName, double aSalary, int aYear, int aMonth, int aDay) {
        name = aName;
        salary = aSalary;
        hireDay = LocalDate.of(aYear,aMonth,aDay);
    }

    // instance methods
    public String getName() {
        return name;
    }
    public double getSalary() {
        return salary;
    }
    public LocalDate getHireDay() {
        return hireDay;
    }
    public void raiseSalary(double byPercent) {
        double raise = salary * byPercent / 100;
        salary += raise;
    }

    //instance fields
    private String name;
    private double salary;
    private LocalDate hireDay;
}
```

```
class Manager extends Employee {  
    public Manager(String name, double salary, int year,  
                  int month, int day) {  
        super(name, salary, year, month, day);  
        bonus = 0;  
    }  
    @Override  
    public double getSalary() {  
        //no direct access to private variables of  
        //superclass  
        double baseSalary = super.getSalary();  
        return baseSalary + bonus;  
    }  
    public void setBonus(double b) {  
        bonus = b;  
    }  
    public double getBonus() {  
        return bonus;  
    }  
    private double bonus;  
}
```

```
class ManagerTest {  
    public static void main(String[] args) {  
        Manager boss = new Manager("Boss Guy", 80000,  
            1987, 12, 15);  
        boss.setBonus(5000);  
  
        Employee[] staff = new Employee[3];  
  
        staff[0] = boss;  
        staff[1] = new Employee("Jimbo", 50000, 1989, 10, 1);  
        staff[2] = new Employee("Tommy", 40000, 1990, 3, 15);  
  
        //print names and salaries  
        for(Employee e : staff) {  
            System.out.println("name: " + e.getName() +  
                "salary: " + e.getSalary());  
        }  
    }  
}
```

Points to observe: (Demo: lesson4.managerinherit)

- Manager provides all the "services" of Employee, with additional functionality (involving bonuses) – so it's a good candidate for *extending* Employee.
- We use the *extends* keyword to indicate that Manager is a *subclass* of Employee
- A Manager instance can freely use the getName and getHireDay methods of its superclass Employee – no need to re-code these methods. However, special methods that are unique to Manager (in particular, the setBonus method) cannot be called on an Employee instance.

```
Manager m = new Manager( . . . );
m.getName();           //ok
m.setBonus(5000);      //ok
```

```
Employee e = new Employee( . . . );
e.getName();           //ok
e.setBonus(5000);    //compiler error
```

- We *override* the `getSalary` method in the `Manager` class.
 - This means that the method has the same signature as the original version in `Employee`, but is defined differently. A `Manager` object computes salary differently from `Employee` objects.
- We still wish to *use* `getSalary` in `Employee`, but add the value of bonus to it. How can this be done?
 - In general, how to access the *superclass version* of a method from within a *subclass*?

Solution: Use `super` to indicate that you are accessing the superclass version.

Best Practice. Use the `@Override` annotation on `getSalary`.

Two reasons :

- It is possible for another user of your code not to realize that your method overrides a method in a superclass.
- Provides a compiler check that your method *really is* overriding a superclass method.

Important Example: Overriding the `equals` method (see below)

- In the Manager constructor, we wish to *reuse* the constructor that is found in Employee, but we also want to include more code. This is accomplished by using the **super** keyword again (but it has a different meaning here).

Like **this** in constructor, the use of **super** to refer to a superclass constructor must occur on the first line of the constructor body.

- *Polymorphic types*. The 0th element of the staff array was defined to be of type Manager, yet we placed it in an array of Employee objects.

```
Manager boss = new Manager(...);  
Employee[] staff = new Employee[3];  
staff[0] = boss;
```

The fact that an object variable can refer to an object of a given type as well as objects that belong to subtypes of the given type is called **polymorphism**.

- *Dynamic binding.* When the `getSalary` method is called on `staff[0]`, the version of `getSalary` that is used is the version that is found *in the Manager class*. This is possible because the JVM keeps track of the actual type of the object (the *runtime type*) when it was created. This type is set with execution of the `new` operator.

The correct method body (the version that is in `Manager`) is associated with the `getSalary` method at runtime – this "binding" of method body to method name is called *late binding* or *dynamic binding*.

Overriding

```
class Dog{  
    public void bark(){  
        System.out.println("woof ");  
    }  
}  
  
class Hound extends Dog{  
    public void sniff(){  
        System.out.println("sniff ");  
    }  
  
    @Override  
    public void bark(){  
        System.out.println("bowl");  
    }  
}
```

Same Method Name,
Same parameter

Overloading

```
class Dog{  
    public void bark(){  
        System.out.println("woof ");  
    }  
  
    //overloading method  
    public void bark(int num){  
        for(int i=0; i<num; i++)  
            System.out.println("woof ");  
    }  
}
```

Same Method Name,
Different Parameter

Dynamic

- Late binding
- Runtime
- Method overriding

Static

- Early binding
- Compile time
- Method overloading

- *Using the instanceof operator to determine the runtime type.* (Because of polymorphism, it is not usually necessary to determine the runtime type of objects)

The following code returns true:

```
"Hello" instanceof java.lang.String
```

In general, you can query Java about the type of any runtime object by using instanceof. The general syntax is

```
ob instanceof <classname>
```

where ob is an object. This expression will return true if the *runtime type* of ob really is of the specified type, or if the class of ob is a subclass of (or a subclass of a subclass of...etc) the specified type. Therefore, for example, if man is an instance of Manager and str is a String, all of the following are true

```
man instanceof Employee  
man instanceof Object  
str instanceof Object
```

Whenever the instanceof operator returns true, the object on the left side of the expression can be viewed as having type indicated on the right side (via polymorphic type assignment). So in this example, we could type man and str above as Objects:

```
Object ob_m = man;  
Object ob_s = str;
```

Exercise 4.1

Which line of code below produces a compiler error?

```
public class Student { ... }
```

```
public class Undergraduate extends Student { ... }
```

```
public class Graduate extends Student { ... }
```

```
Student st1, st2, st3;
```

```
Graduate st4;
```

```
st1 = new Student();
```

```
st2 = new Undergraduate();
```

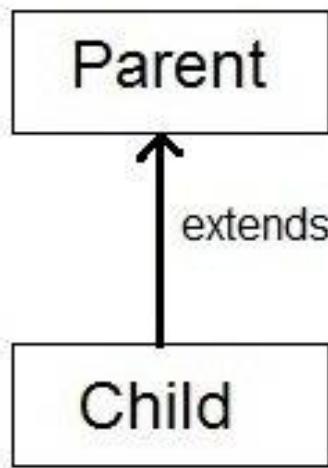
```
st3 = new Graduate();
```

```
st4 = new Student();
```

Solution

```
public class Student { ... }
public class Undergraduate extends Student { ... }
public class Graduate extends Student { ... }

Student st1, st2, st3;
Graduate st4;
st1 = new Student();
st2 = new Undergraduate();
st3 = new Graduate();
st4 = new Student(); ← //compiler error
```



Parent p = new Child();

Upcasting

Child c = ~~new~~ Parent();

Compile time error

Child c = (Child) new Parent();

Downcasting but throws
ClassCastException at runtime.

Main Point

One class (the *subclass*) inherits from another class (the *superclass*) if all protected and public data and methods in the superclass are automatically accessible to the subclass, even though the subclass may have additional methods and data not found in the superclass. Java supports this notion of *inheritance*. In Java syntax, a class is declared to be a subclass of another by using the *extends* keyword. Likewise, individual intelligence "inherits from" cosmic intelligence, though each "implementation" is unique.

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Correct Use of Inheritance

Here are two tests to check whether one class should inherit from another.

- Manager **IS-A** Employee – it's not just that the two classes have some methods in common, but a manager really is an employee. This helps to verify that inheritance is the right relationship between these classes.
- *Liskov Substitution Principle (LSP)*. Another test is: Can a Manager instance be used whenever an Employee instance is expected? The answer is yes, since every manager really is an employee, and partakes of all the properties and behavior of an employee, though managers support extra behavior.

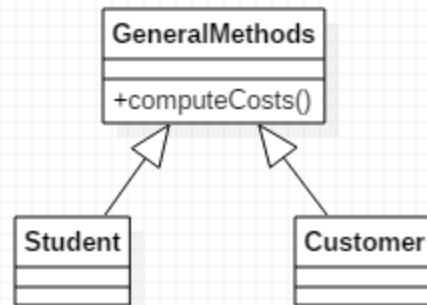
Common Mistake: Indiscriminate Generalization

- The following strategy is a mistake: Place methods common to several classes into one superclass for all of them. Then all the classes have immediate access to methods that they all can use.

This is undesirable because, eventually, some methods and variables in the superclass will not be relevant for some of the subclasses – those subclasses will therefore offer "services" that they cannot possibly provide.

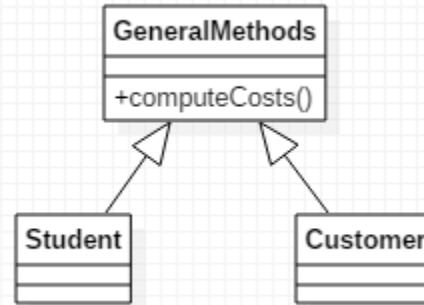
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- At first, this may seem reasonable

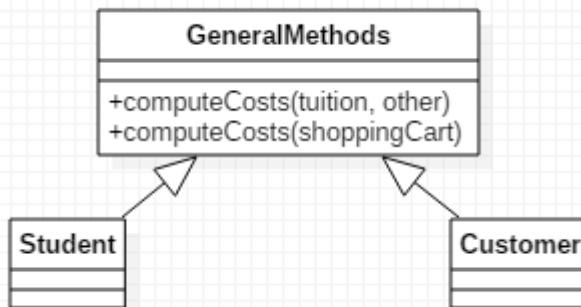


(continued)

- At first, this may seem reasonable



- As your project evolves, you may find that different versions of computeCosts are needed for Student and Customer



Now a `Customer` seems to be supporting `computeCosts` with input `tuition` and `other`. This undermines the purpose of the `Customer` class

(continued)

- A better approach is to place commonly used methods in a *utility class*.

```
public class Student {  
    void aMethod() {  
        double tuition = 5000;  
        double other = 3000;  
        //...  
        double val = Util.computeCosts(tuition, other);  
        //...  
    }  
  
    public class Customer {  
        void aMethod() {  
            ShoppingCart cart = new ShoppingCart();  
            //...populate cart  
            double val = Util.computeCosts(cart);  
            //...  
        }  
    }  
}
```

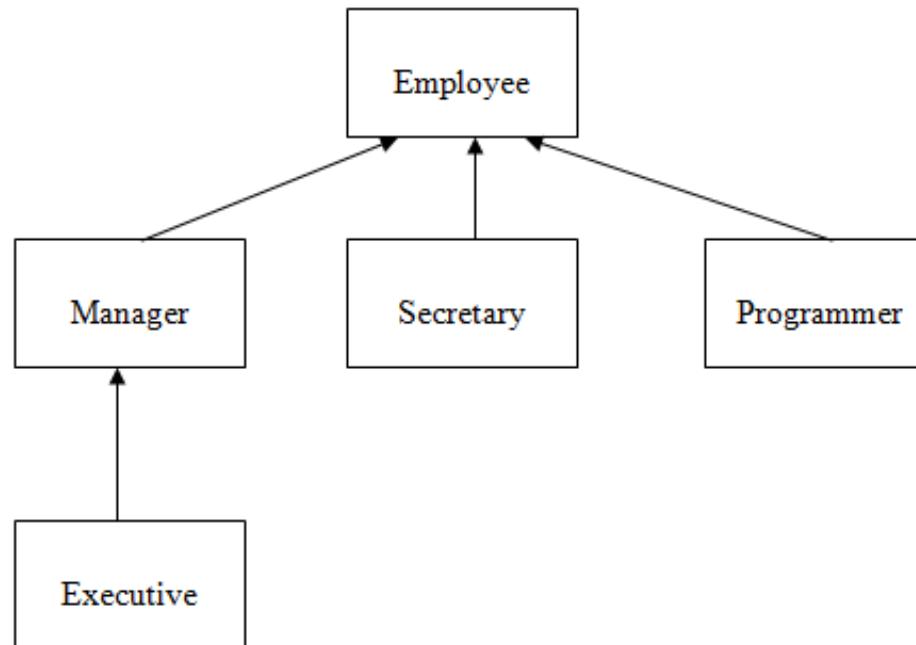
```
public class Util {  
    private Util() {  
        //private constructor  
    }  
    public static double computeCosts(double tuition, double other) {  
        double cost = 0.0;  
        //...compute  
        return cost;  
    }  
  
    public static double computeCosts(ShoppingCart cart) {  
        double cost = 0.0;  
        //unpack cart and compute  
        return cost;  
    }  
}
```

Preventing/restricting inheritance

- Declaring a class to be final prevents creation of any subclass (recall: this is one of the techniques used to ensure that a class is *immutable*)
- Declaring a method to be final prevents any subclass from overriding it

Inheritance hierarchies

- Sometimes a subclass of a class is further extended by another subclass. Repeated subclassing results in an *inheritance hierarchy*.



Main Point

As a matter of good design, a class C should not be made a subclass of a class D unless C "IS-A" D. Likewise, individual intelligence "is" cosmic intelligence, though this relationship requires time to be recognized as true.

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Rules for Subclass Constructors

The Rule:

a subclass constructor must make use of one of the constructors from its superclass

Reason for the rule The state of the superclass (values of its instance variables) should be set by *the superclass* (not by the subclass). So, during construction, the subclass must request the superclass to first set its state, and then the subclass may perform further initialization of its own state.

Example. Employee/Manager:

```
class Employee{  
    Employee(String name, double salary, int y, int m, int d){  
        //.../  
    }  
}  
class Manager extends Employee {  
    Manager(String name, double salary, int y, int m, int d) {  
        super(name,salary,y,m,d); //makes use of superclass constructor  
    }  
}
```

Note: It is not necessary for any of the subclass constructors to have the same signature as any of the superclass constructors. However, each of the subclass constructors must access one of the superclass constructors in its implementation.

```
class Employee{  
    Employee(String name, double salary, int y,  
             int m, int d) {  
        //...//  
    }  
}  
class Manager extends Employee {  
    Manager(String name, double salary,  
            double bonus, //different but ok  
            int y, int m, int d) {  
        super(name,salary,y,m,d);  
        this.bonus = bonus;  
    }  
}
```

The subclass may make use of the implicit default constructor *only if* either

- A. the no-argument constructor of the superclass has been explicitly defined,
OR
- B. no constructor in the superclass is explicitly defined

In either of these cases, the subclass may make use (possibly implicitly) of the superclass' s default constructor.

```
//Case A.  
class Employee{  
    Employee(String name, double salary, int y, int m, int d) {  
        //...//  
    }  
    //explicit coding of default constructor since another  
    //constructor is present  
    Employee() {  
        //...//  
    }  
}  
class Manager extends Employee {  
    //no explicit constructor call here, so the superclass  
    //default constructor is used implicitly  
}
```

```
//Case B.

class Superclass{
    //...//
}

class Subclass extends Superclass {
    //...//
}

class Callingclass {
    public static void main(String[] args) {
        Superclass s = new Subclass(); //this is ok
    }
}
```

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Inheritance and the Object Class

- In Java, there is a class called `Object`. Every class created in Java (either in the Java libraries, or user-defined) belongs to the inheritance hierarchy of `Object`.

For example:

```
class MyClass {  
}
```

This `MyClass` class automatically inherits from `Object`, even though we do not write syntax that declares this fact.

In later slides, we will discuss the (primarily public) methods that belong to `Object`, and that are therefore inherited by every class in Java.

Exercise 4.2 – the Object class

One of the public methods in `Object` is `toString()`. This method returns a `String` representation of a given object.

The code to the right uses the fact that every class automatically inherits the `toString()` method from `Object`.

What will be the output when the `main` method is run? Is this output a useful representation of the `Employee` class?

What could be done to make it more useful?

```
public class Employee {  
    private String name;  
    private int salary;  
    public Employee(String name, int salary) {  
        this.name = name;  
        this.salary = salary;  
    }  
    public String getName() {  
        return name;  
    }  
    public int getSalary() {  
        return salary;  
    }  
  
    public static void main(String[] args) {  
        Employee e = new Employee("Bob", 85000);  
        System.out.println(e.toString());  
    }  
}
```

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Two Ways Inheritance Arises

- We saw Manager was a natural choice for a *subclass* of Employee because it *extends* Employee's behavior.
- Another situation that gives rise to inheritance occurs when several classes are seen to naturally belong to the same general type – this is *generalization*.

In the "figures" example (next slide), it seems natural to generalize the curves Triangle, Circle, Square

```
final class Triangle {  
    final double base;  
    final double height;  
    Triangle(double base, double height) {  
        . . .  
    }  
    double computeArea() {  
        return (0.5 * base * height);  
    }  
}
```

```
final class Square {  
    final double side;  
    Square(double side) {  
        this.side = side;  
    }  
    double computeArea() {  
        return(side*side);  
    }  
}  
  
final class Circle {  
    final double radius;  
    Circle(double radius) {  
        this.radius = radius;  
    }  
    double computeArea() {  
        return (Math.PI * radius * radius);  
    }  
}
```

Demo: lesson4.closedcurve.bad

```
//Illustrates a non-OO (= bad) way of computing areas
class Test {
    public static void main(String[] args) {
        Object[] objects = {new Triangle(3,3),
                            new Square(3),
                            new Circle(3)};
        //compute areas
        for(Object o : objects) {
            if(o instanceof Triangle) {
                Triangle t = (Triangle)o;
                System.out.println(t.computeArea());
            }
            if(o instanceof Square) {
                Square s = (Square)o;
                System.out.println(s.computeArea());
            }
            if(o instanceof Circle) {
                Circle c = (Circle)o;
                System.out.println(c.computeArea());
            }
        }
    }
}
```

Points:

- Notice we can arrange Triangle, Square, Circle into an array of type Object[] by polymorphism. But Object does not have a computeArea method, so we cannot polymorphically compute areas by using a single superclass method computeArea.
- Instead, if we use an array Object[], we have to repeatedly test the type of the Object in the area in order to execute the correct computeArea method (using the instanceof operator).
- This approach needs improvement! (You should never write code that looks like this!)

Towards an OO Solution

- Can **generalize** the behavior of these geometric shape classes to support *polymorphic* access to a **general** computeArea method.

```
abstract class ClosedCurve {  
    abstract double computeArea();  
}
```

The keyword `abstract` on a method means the method is *unimplemented*

```
final class Triangle extends ClosedCurve {  
    final double base;  
    final double height;  
  
    Triangle(double base, double height) {  
        . . .  
    }  
    double computeArea() {  
        return (0.5 * base * height);  
    }  
}
```

```
final class Square extends ClosedCurve {
    final double side;
    Square(double side) {
        this.side = side;
    }
    double computeArea() {
        return(side*side);
    }
}
final class Circle extends ClosedCurve {
    final double radius;
    Circle(double radius) {
        this.radius = radius;
    }
    double computeArea() {
        return (Math.PI * radius * radius);
    }
}
```

```
//This is the OO (= good) way of computing areas

class Test {
    public static void main(String[] args) {

        ClosedCurve[] objects = {new Triangle(3,3),
                                  new Square(3),
                                  new Circle(3)};
        //compute areas
        for(ClosedCurve cc : objects) {

            System.out.println(cc.computeArea());
        }
    }
}
```

Points

1. No testing of types is required to access the computeArea method
2. New types of objects (such as Rectangle) can now be introduced by adding new subclasses to ClosedCurve. The only change to the code that is needed is inclusion of new instances in the ClosedCurve [] array, when it is initialized.

This is an example of the *Open-Closed Principle*: a well-designed OO program is open to extension but closed to modification.

3. Points about the code: The *abstract* keyword.

- ❖ If a class is declared *abstract*, it cannot be instantiated.
- ❖ If a method is declared abstract, it cannot have a body -- it can only be declared.
- ❖ If a class has at least one abstract method, the class must be declared abstract.
- ❖ A subclass of an abstract class must implement (provide method bodies for) every abstract method in its superclass (or else declare unimplemented methods abstract).
- ❖ An abstract class is used to declare "services" that it provides. Any subclass of an abstract class promises to make those services available, though different subclasses may accomplish this in different ways (the method `computeArea` is an example of this).
- ❖ Abstract classes may include instance variables and other non-abstract (implemented) methods.

Variable Access Does Not Use Dynamic Binding

- Access of variables does not use dynamic binding. The variable value is associated with the static type at compile time

- In the Sup class, the code

```
Sup s = new Sub();
int z = s.x;
```

is not concerned with the runtime type of s -- so the value of x that is used is the value contained in the superclass Sup.

```
public class Sup {
    private int x = 1;

    public static void main(String[] args) {
        Sup s = new Sub();
        System.out.println(s.x);
    }
}
```

//output: 1 (not 2)

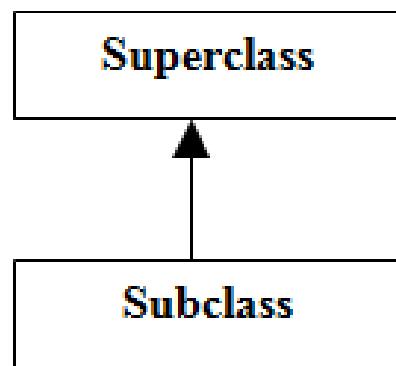
```
public class Sub extends Sup{
    int x = 2;

    public static void main(String[] args) {
        Sup s = new Sub();
        //int z = s.x; //doesn't compile
    }
}
```


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 - The `hashCode` Method

Order of Execution with Inheritance



Suppose, as in a typical case, we have `Subclass` as a subclass of `Superclass`. When we run

```
new Subclass()
```

the sections of the code are executed according to the following scheme:

- In Superclass, all static variables are initialized and all static initialization blocks are run, in the order in which they appear in the file.
- In Subclass, all static variables are initialized and static initialization blocks are run, in the order in which they appear in the file.
- In Superclass, all instance variables are initialized and all object initialization blocks are run, in the order in which they appear in the file
- In Superclass, the (relevant) constructor is run.
- In Subclass, all instance variables are initialized and all object initialization blocks are run, in the order in which they appear in the file
- In Subclass, the (relevant) constructor is run.

[See Demo – lesson4.orderofexec]

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Introduction to Java Interfaces

A Java *interface* is like an abstract class except:

- No instance variables (other than variables declared final) or implemented methods can occur
- An interface is declared using the *interface* keyword, not the *class* keyword
- A class that implements an interface uses the *implements* keyword rather than the *extends* keyword
- Can implement more than one interface. Syntax:
`MyClass implements Interface1, Interface2, Interface3`

Can also extend *and* implement. Syntax:

`MyClass extends SuperClass implements Interface1, Interface2`

However, no class can have more than one superclass. (Multiple inheritance not supported)

- When a class implements an interface, it must implement (or declare as abstract) all unimplemented methods in the interface.
- In the earlier example, `ClosedCurve` could have been made to be an interface. The code would have looked like the following:

```
public interface ClosedCurve {
    double computeArea();
}

class Triangle implements ClosedCurve {
    double base;
    double height;
    Triangle(double side1,
             double side2, double side3) {
        double[] arr = sort(side1,side2,side3);
        double x = arr[0];
        double y = arr[1];
        double z = arr[2];
        if(x + y < z) {
            System.out.println("Illegal sizes for a triangle:
                               "+side1+", "+side2+", "+side3);
            System.out.println("Using default sizes.");
            computeBaseAndHeight(DEFAULT_SIDE,
                                 DEFAULT_SIDE,DEFAULT_SIDE);
        }
        else {
            //method body not shown
            computeBaseAndHeight(x,y,z);
        }
    }
    double computeArea() {
        return (0.5 * base * height);
    }
}
```

```
class Square implements ClosedCurve {  
    double side;  
    Square(double side) {  
        this.side = side;  
    }  
    double computeArea() {  
        return(side*side);  
    }  
}  
class Circle implements ClosedCurve {  
    double radius;  
    Circle(double radius) {  
        this.radius = radius;  
    }  
    double computeArea() {  
        return (Math.PI * radius * radius);  
    }  
}
```

```
class Test {  
    public static void main(String[] args) {  
        ClosedCurve[] objects = {new Triangle(5, 5),  
                                new Square(3),  
                                new Circle(3)};  
        //compute areas  
        for(ClosedCurve cc : objects) {  
            System.out.println(cc.computeArea());  
        }  
    }  
}
```

Note. This example illustrates the fact that a class that implements an interface may be cast as the type of that interface. A simple instance of this, like the example above, would be:

```
ClosedCurve cc = new Rectangle(2, 4);
```

Interfaces in the Java Library: Comparable

- The `compareTo` method in `String`, `Integer`, `Double`, etc, is in every case an implementation of Java's `Comparable` interface.
- For Strings, the interface looks like this:

```
interface Comparable<String> {
    public int compareTo(String s);
}

class String implements Comparable<String> {
    ...
}
```

- In the Java library, `Comparable` is defined *generically*, for any possible type, like this:

```
interface Comparable<T> {
    public int compareTo(T s);
}
```

Note: Generic types will be discussed more in Lesson 8

Functional Interfaces

- Whenever an interface has *just one abstract method*, the interface is called a *functional interface*. The reason for the terminology is that, since there is just one abstract method, implementations of a functional interface behave like a *function*.
- Comparable is an example of a functional interface
- Functional interfaces have become an important aspect of Java since Java SE 8 because implementations can be represented using *lambda expressions*.

User-Defined Functional Interfaces

- Defining your own functional interface is easy, but if you want to use it in the context of new Java 8 features, you have to prevent other developers from accidentally adding methods to your interface. This can be done by using the `@FunctionalInterface` annotation.

```
@FunctionalInterface  
public interface MyFunctional {  
    void myMethod(String t);  
  
    //if uncommented, there will be a compiler error  
    //int anotherMethod(int x);  
}
```

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 - The `clone` Method, the `protected` Keyword and Shallow and Deep Copies

Interface Features, New in Java 8

- Before Java 8, as we have seen, none of the methods in an interface had a method body; all were unimplemented.
- Since Java 8, two kinds of implemented methods are allowed: *default methods* and *static methods*. Both can be added to legacy interfaces without breaking code.
 - A default method is a fully implemented method within an interface, whose declaration begins with the keyword `default`
 - A static method is a fully implemented method within an interface, having the same characteristics as any static method in a class.
- Demo: package lesson4.java8interface

Interfaces in Java 7 and Java 8

Interview Question: What is the difference between an abstract class and an interface?

Answer from the perspective of Java 7 (and before)

- Abstract classes may have fully implemented methods, but interfaces may not
- Abstract classes may contain static methods while interfaces may not
- Abstract classes may have instance variables of any kind, whereas interfaces can have only public final variables
- All methods in an interface are public, but abstract classes may have implemented methods of any visibility and abstract methods that are either public or protected

Answer from the perspective of Java 8 (and after)

- Abstract classes may have fully implemented instance methods; interfaces may also have implemented instance methods, but they must bear the keyword “default”
- Abstract classes may have instance variables of any kind, whereas interfaces can have only public final variables
- All methods in an interface are public, but abstract classes may have implemented methods of any visibility and may have abstract methods that have public, protected, or package-level visibility

Main Point

Interfaces are used in Java to specify publicly available services in the form of method declarations. A class that implements such an interface must make each of the methods operational. Interfaces may be used polymorphically, in the same way as a superclass in an inheritance hierarchy. Because many interfaces can be implemented by the same class, interfaces provide a safe alternative to multiple inheritance. The concept of an interface is analogous to the creation itself – the creation may be viewed as an “interface” to the undifferentiated field of pure consciousness; each object and avenue of activity in the creation serves as a reminder and embodiment of the ultimate reality.

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Introduction to Java's Reflection Library

- Reflection in Java allows an object to
 - determine information about other objects at runtime (such as attributes, methods, constructors)
 - instantiate another object given just the name of the class (and names or types of the parameters passed to the constructor, if any)
 - call a function based only on the name of the function, the class to which it belongs, and the names or types of the function arguments, if any
- For this course, we will see how Reflection can work in conjunction with polymorphism. We will see how techniques of Reflection give us more flexibility in creating polymorphic code.

Challenge: Accessing Types without Violating the Open-Closed Principle

In the ClosedCurve example, how can we make it so that not only is each area printed out in the for each loop, but also the *type* of closed curve, as in the following:

```
The area of this Triangle is 12.5  
The area of this Square is 9.0  
The area of this Circle is 28.274
```

We do not want to test the type of each object in the array – this would violated the Open-Closed Principle. How can we output the type of each object in a generic way?

```
public class Test {  
    public static void main(String[] args) {  
        ClosedCurve[] objects = {new Triangle(5,5),  
                                new Square(3), new Circle(3)};  
        //compute areas  
        for(ClosedCurve cc : objects) {  
            System.out.println(cc.computeArea());  
        }  
    }  
}
```

Solution: Use the *Class* Class

1. The Java runtime keeps track of "runtime type information" about each object. This information includes the class to which it belongs, the name of that class, and many details about the structure of the class.
2. This information is accessible through an object's `Class`. The `Class` to which an object belongs is obtained like this:

```
String s = "Hello";  
Class cl = s.getClass(); //cl represents the String class
```

This same class can be specified in two other ways:

```
Class cl2 = String.class;  
System.out.println(cl == cl2); //true
```

```
Class cl3 = Class.forName("java.lang.String");  
System.out.println(cl == cl3); //true
```

3. From the name of the class, the Class can be discovered. Conversely, from the Class instance, the name of the class can be discovered:

```
// "java.lang.String"  
String name = "Hello".getClass().getName();
```

```
// "String"  
String name3 = "Hello".getClass().getSimpleName();
```

Application: These features of the Class class allow us to solve the Challenge:

```
public class TestSecond {  
  
    public static void main(String[] args) {  
  
        ClosedCurve[] objects = {new Triangle(10, 9, 6),  
                                new Square(3),  
                                new Circle(3)};  
        //compute areas  
        for(ClosedCurve cc : objects) {  
            String nameOfCurve = cc.getClass().getSimpleName();  
            System.out.printf("The area of this %s is %.2f \n",  
                            nameOfCurve, cc.computeArea());  
        }  
    }  
}
```

Exercise 4.3: Using Reflection

Reflection can be used to create an instance of a class just by supplying the *name* of class. This exercise gives an example of this kind of code. Try running the code shown here (it is in the InClassExercises project). Try to explain how the code works.

```
public class Employee {  
    private String name;  
    private int salary;  
    public Employee() {  
        //creates an Employee shell  
    }  
    public String getName() {  
        return name;  
    }  
    public int getSalary() {  
        return salary;  
    }  
    public void setName(String name) {  
        this.name = name;  
    }  
    public void setSalary(int sal) {  
        this.salary = sal;  
    }  
    @Override  
    public String toString() {  
        return name + ": " + salary;  
    }  
}
```

```
public class Main {  
    public static void main(String[] args)  
        throws ClassNotFoundException, InstantiationException,  
        IllegalAccessException, IllegalArgumentException,  
        InvocationTargetException, NoSuchMethodException,  
        SecurityException {  
  
        String className = "lesson4.exercise_3.Employee";  
        Class<?> empClass = Class.forName(className);  
        Employee emp = (Employee)empClass.getDeclaredConstructor().newInstance();  
        emp.setName("Bob");  
        emp.setSalary(85000);  
        System.out.println(emp);  
    }  
}
```

Solution

```
public class Employee {  
    private String name;  
    private int salary;  
    public Employee() {  
        //creates an Employee shell  
    }  
    public String getName() {  
        return name;  
    }  
    public int getSalary() {  
        return salary;  
    }  
    public void setName(String name) {  
        this.name = name;  
    }  
    public void setSalary(int sal) {  
        this.salary = sal;  
    }  
    @Override  
    public String toString() {  
        return name + ": " + salary;  
    }  
}
```

```
public class Main {  
    public static void main(String[] args)  
        throws ClassNotFoundException, InstantiationException,  
        IllegalAccessException, IllegalArgumentException,  
        InvocationTargetException, NoSuchMethodException,  
        SecurityException {  
  
        String className = "lesson4.exercise_3.Employee";  
  
        //creates a Class object based on String name  
        Class<?> empClass = Class.forName(className);  
  
        //locates the no-argument constructor for Employee and invokes it  
        Employee emp = (Employee)empClass.getDeclaredConstructor().newInstance();  
  
        //sets name and salary in the Employee shell  
        emp.setName("Bob");  
        emp.setSalary(85000);  
  
        //invokes Employee's toString method  
        System.out.println(emp);  
    }  
}
```

Note: Frameworks, like Spring, make use of this kind of Reflection to create instances of objects at the startup of an application.

Main Point

The classes in the Java Reflection package can be used to construct an instance of a class (with parameters) from a String (which stores the name of the class) or Class object; similarly, it is possible to invoke a method on another class (with parameters) simply by knowing the String name of the method. In a parallel fashion, according to ancient wisdom, it is possible to experience the subtlest value of the name of an object – at a level where the impulses that structure the name are the same as those that structure the object. Working at that level, by invoking the name of the object, the object can be made to appear.

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The Object Class

- *Singly-rooted.* Every Java class belongs to one large inheritance hierarchy in which Object is at the top. No explicit mention of "extending" Object needs to be made in your code – it is already understood by the compiler and JVM.
- Every class has access to the following methods (and others that we will not cover here):
 - public String toString()
 - public boolean equals(Object o)
 - public int hashCode() [See Lesson 11]
 - protected Object clone() throws CloneNotSupportedException

The `toString` Method

1. If a class does not override the default implementation of `toString` given in the `Object` class, it produces output like the following:

```
public static void main(String[] args) {  
    System.out.println(new Object());  
    System.out.println(new StoreDirectory(null));  
  
}  
  
//output  
java.lang.Object@18d107f  
scope.more.StoreDirectory@ad3ba4
```

This is a concatenation of the fully qualified class name with the hexadecimal version of the "hash code" of the object (we will discuss hash codes in Lesson 11)

2. Most Java API classes override this default implementation of `toString`. The purpose of the method is to provide a (readable) String representation (which can be logged or printed to the console) of the state of an object.

Example from the Exercises:

```
// the Account object has this implementation of  
// toString  
public String toString() {  
    String ret =  
        "Account type: " + acctType +  
        "\nCurrent bal: " + balance;  
    return ret;  
}
```

Best Practice. For every significant class you create, override the `toString` method.

- 3.** `toString` is automatically called when you pass an object to `System.out.println` or include it in the formation of a `String`
- 4.** Examples:

```
Account acct = . . . //populate an  
AccountString output = "The account: " + acct;
```

```
Account acct = . . . // populate an Account  
System.out.println(acct);
```

5. toString for arrays – sample usage

Suppose we have the array

```
String[] people = {"Bob", "Harry", "Sally"};
```

- Wrong way to form a string from an array

```
people.toString()  
//output: [Ljava.lang.String;@19e0bfd
```

- Right way to form a string from an array

```
Arrays.toString(people)  
//output: [Bob, Harry, Sally]
```

The equals Method

- Implementation in Object class:

`ob1.equals(ob2)` if and only if `ob1 == ob2`
if and only if references point to the same object

Using the '`==`' operator to compare objects is usually not what we intend (though for comparison of *primitives*, it is just what is needed). For comparing objects, the `equals` method should (usually) be overridden to compare the *states* of the objects.

Example:

```
class Person {  
    private String name;  
    Person(String n) {  
        name = n;  
    }  
}
```

Here, two `Person` instances should be "equal" if they have the same name.
Next slide shows a good way to override `equals`

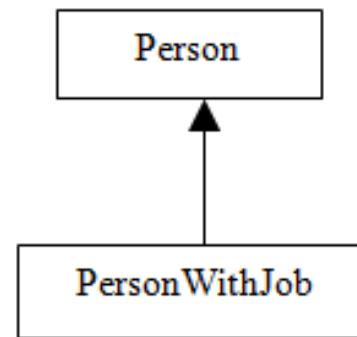
```
//an overriding equals method in the Person class
@Override
public boolean equals(Object aPerson) {
    if(aPerson == null) return false;
    if(!(aPerson instanceof Person)) return false;
    Person p = (Person)aPerson;
    boolean isEqual = this.name.equals(p.name);
    return isEqual;
} //see lesson4.equals.simple
```

Things to notice:

- The argument to `equals` must be of type `Object` (otherwise, compiler error)
- If input `aPerson` is `null`, it can't possibly be equal to the current instance of `Person`, so `false` is returned immediately
- If runtime type of `aPerson` is not `Person` (or a subclass), there is no chance of equality, so `false` is returned immediately
- After the preliminary special cases are handled, two `Person` objects are declared to be equal if and only if they have the same name.

Handling equals() in Inherited Classes

Example: Add a subclass `PersonWithJob` to `Person`:



```

class Person {
    private String name;
    Person(String n) {
        name = n;
    }
    public String getName() {
        return name;
    }
    @Override
    public boolean equals(Object aPerson) {
        if(aPerson == null) return false;
        if(!(aPerson instanceof Person)) return false;
        Person p = (Person)aPerson;
        boolean isEqual = this.name.equals(p.name);
        return isEqual;
    }
}
class PersonWithJob extends Person {
    private double salary;
    PersonWithJob(String n, double s) {
        super(n);
        salary = s;
    }
}

```

The `equals()` method is inherited by `PersonWithJob` in this implementation. So objects of type `PersonWithJob` are compared only on the basis of the name field.

Example:

```
PersonWithJob joel = new PersonWithJob("Joe", 100000);
PersonWithJob joe2 = new PersonWithJob("Joe", 50000);
boolean areTheyEqual = joel.equals(joe2); //areTheyEqual
                                         == true
```

Best Practices: If, in your code, this kind of situation does not present a problem – if it is OK to inherit `equals()` in this way – then the implementation given here is optimal. This is called the *instanceof strategy for overriding equals*

Best practice in the case where subclasses need to have their own form of `equals` is more complicated (discussed below)

What Happens When Subclasses Need Their Own Form of equals()

Example. Provide PersonWithJob its own equals method.

Demo: lesson4.equals.asymmetry

```
//an overriding equals method in the PersonWithJob class
@Override
public boolean equals(Object withJob) {
    if(withJob == null) return false;
    if(!(withJob instanceof PersonWithJob))
        return false;
    PersonWithJob p = (PersonWithJob)withJob;
    boolean isEqual= getName().equals(p.getName()) &&
                    this.salary == p.salary;
    return isEqual;
}
```

This creates a serious problem, called *asymmetry*
(violates contract for equality)

```
Person p = new Person("Joe");
PersonWithJob withJob = new PersonWithJob("Joe",
                                          100000);

//true - using Person's equals()
theyreEqual1 = p.equals(withJob);

//false - using PersonWithJob's equals()
theyreEqual2 = withJob.equals(p);
```

Example. Implement equals in a different way for both Person and PersonWithJob.

Demo: lesson4.equals.sameclass

```
//alternative equals method in the Person class
@Override
public boolean equals(Object aPerson) {
    if(aPerson == null) return false;
    if(aPerson.getClass() != this.getClass())
        return false;
    Person p = (Person)aPerson;
    boolean isEqual = this.name.equals(p.name);
    return isEqual;
}

//alternative equals method in the PersonWithJob class
@Override
public boolean equals(Object withJob) {
    if(withJob == null) return false;
    if(withJob.getClass() != this.getClass())
        return false;
    PersonWithJob p = (PersonWithJob)withJob;
    boolean isEqual = getName().equals(p.getName()) &&
                     this.salary == p.salary;
    return isEqual;
}
```

This solves the asymmetry problem – now, it is impossible for a PersonWithJob object to be equal to a Person object, using either of the equals () methods. This is called the *same classes strategy for overriding equals.*

Difficulty with the Same Classes Strategy

Example: Continuing the example from above, suppose we have a subclass PersonWithJobWithCounter of PersonWithJob.

Demo: lesson4.equals.sameclass.theproblem

```
//using same classes strategy as shown earlier
class PersonWithJob extends Person {
    private double salary;
    PersonWithJob(String n, double s) {
        super(n);
        salary = s;
    }
    @Override
    public boolean equals(Object withJob) {
        if(withJob == null) return false;
        if(withJob.getClass() != this.getClass())
            return false;
        PersonWithJob p = (PersonWithJob)withJob;
        boolean isEqual =
            getName().equals(p.getName()) &&
            this.salary == p.salary;
        return isEqual;
    }
}
```

```
class PersonWithJobWithCounter
    extends PersonWithJob {
    static private int counter;
    PersonWithJobWithCounter(String n, double s) {
        super(n, s);
        counter++;
    }
}
```

The intention here is that `PersonWithJobWithCounter` will use the equals method of its superclass. But this creates a problem:

```
PersonWithJob joel =
    new PersonWithJob("Joe", 50000);
PersonWithJobWithCounter joe2 = new
    PersonWithJobWithCounter("Joe", 50000);
joe2.equals(joel); //value is false since joe2
                  //is not of same type as joel
```

Best Practice When Using Same Classes Strategy

The example shows that whenever the same classes strategy is used to provide separate `equals` methods for classes B and A, where B is a subclass of A, then we should prevent the possibility of creating a subclass of B to prevent the introduction of unexpected results of `equals` method.

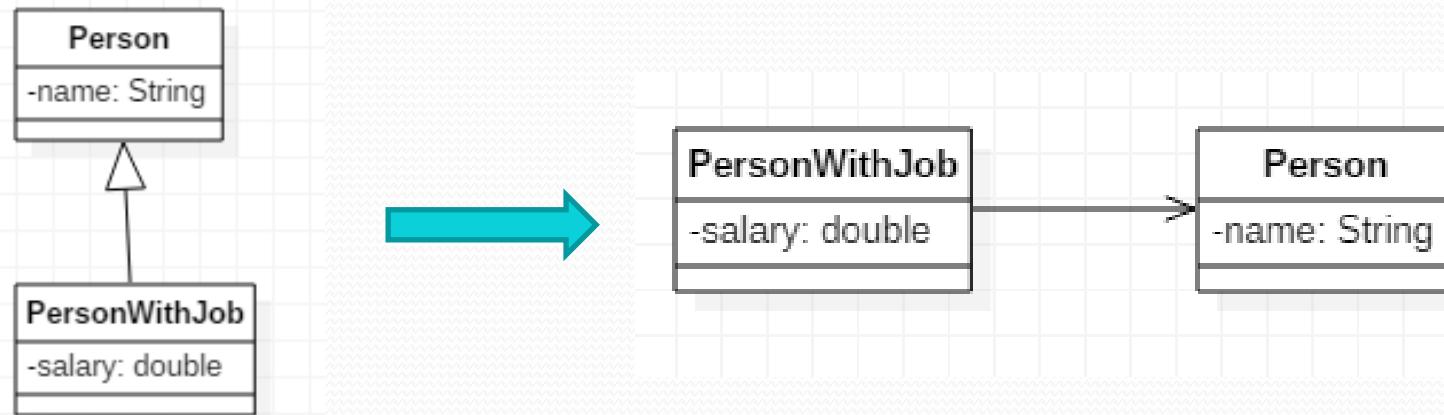
Best Practice – Same Classes Strategy. If B is a subclass of A and each class has its own `equals` method, implemented using the same classes strategy, then the class B should be declared `final` to prevent unexpected result of applying `equals` in a subclass of B.

Question. What if we don't wish to make B `final`?

Using Composition Instead of Inheritance

Previous example shows that when a class B inherits from a class A and you want B and A to have different equals methods, you need to use the same classes strategy and you have to make B final. This procedure is somewhat error-prone (you may forget to make B final) and may not even be desirable (your design may require you to allow B to have subclasses).

An alternative to the same classes strategy, when you need classes A and B to have separate equals methods, is *to use composition instead of inheritance*. In that case, B does *not* inherit from A. This is always a good alternative unless you are needing to use polymorphism.



Example: *Implementing Manager using Composition instead of Inheritance*
(See sample code in package `lesson4.empmanager.usecomposition`)

Summary of Best Practices for Overriding Equals In the Context of Inheritance

Suppose B is a subclass of A.

- If it is acceptable for B to use the same equals method as used in A, then the best strategy is the *instanceof strategy*
- If *two different equals methods* are required, two strategies are possible
 - Use the same classes strategy, but declare subclass B to be final
 - Use composition instead of inheritance – this will always work as long as the inheritance relationship between B and A is not needed (e.g. for polymorphism)

Exercise 4.4: Overriding Equals

In the Employee class, an equals method has been provided. Does equals perform as expected when it is tested in the Main class? What is wrong? How can the problem be fixed? The code is in the InClassExercises project.

```
public class Employee {  
    private String name;  
    private int salary;  
    public Employee(String name, int sal) {  
        this.name = name;  
        this.salary = sal;  
    }  
    public String getName() {  
        return name;  
    }  
    public int getSalary() {  
        return salary;  
    }  
    @Override  
    public String toString() {  
        return name + ": " + salary;  
    }  
    public boolean equals(Employee emp) {  
        if(emp == null) return false;  
        if(emp.getClass() != getClass()) return false;  
        return name.equals(emp.name) && salary == emp.salary;  
    }  
}
```

```
public class Main {  
    public static void main(String[] args) {  
        testEquals1();  
        testEquals2();  
    }  
    private static void testEquals1() {  
        Employee e1 = new Employee("Bob", 85000);  
        Employee e2 = new Employee("Bob", 85000);  
        System.out.println("Are e1 and e2 equal? " + e1.equals(e2));  
    }  
    private static void testEquals2() {  
        Employee[] arr = new Employee[3];  
        arr[0] = new Employee("Bob", 85000);  
        arr[1] = new Employee("Steve", 95000);  
        arr[2] = new Employee("Dave", 105000);  
        Employee bob = new Employee("Bob", 85000);  
        System.out.println("Is bob in the array? "  
            + objectInArray(arr, bob));  
    }  
    private static boolean objectInArray(Object[] arr, Object b) {  
        for(Object e: arr) {  
            if(e.equals(b)) return true;  
        }  
        return false;  
    }  
}
```

Summary

1. Inheritance provides subclasses with access to data and methods that may be inaccessible to other classes.
2. Inheritance supports polymorphism, which makes it possible to perform operations on many different types by performing those operations on just one supertype.
3. Inheritance must be used wisely; the IS-A and LSP criteria provide guidelines for when subclassing can be used safely.
4. Java interfaces provide even more abstraction of classes, and also support polymorphism.
5. As of Java 8, static and default methods may be included in a Java interface.
6. Java's Reflection library makes it possible at runtime for objects to instantiate classes based only on their name and constructor argument types, and to examine the structure of objects at runtime. These tools can provide a powerful addition to OO programming techniques; they play a fundamental role in the design of modern frameworks, like Spring.
7. The Object class is the single root of the inheritance hierarchy that includes all Java classes. Consequently, every Java class, including user-defined classes, automatically inherits several methods defined in Object: equals, hashCode, and toString. Whenever these methods are needed, their default implementation in Object typically needs to be overridden by in user-defined classes.

Connecting the Parts of Knowledge With the Wholeness of Knowledge

Using Reflection to create objects at the level of "name"

1. Ordinarily, an object of a certain type is created in Java by calling the constructor of the class that realizes this type. This is object construction on the level of *form*.
 2. Java's Reflection API allows the developer to construct an object based on the knowledge of the name (and the number and types of arguments required by the constructor). This is object construction on the level of *name*.
-

3. **Transcendental Consciousness:** The fundamental impulses that structure both the name and form of an object have their basis in the silent field of pure consciousness.
4. **Wholeness moving within itself:** In Unity Consciousness, the finest structuring mechanics of creation are appreciated as modes of vibration of the Self.