Chapter 4

Polymorphism

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Objectives

- After you have read and studied this chapter, you should be able to

  - Write programs that are easily extensible and modifiable by applying polymorphism in program design.
  - Define reusable classes based on inheritance and abstract classes and abstract methods.
  - Differentiate the abstract classes and Java interfaces.
  - Define methods, using the **protected** modifier.
  - Parse strings, using a **String Tokenizer** object.

Introduction to Polymorphism

- There are three main programming mechanisms that constitute object-oriented programming (OOP)
  - Encapsulation
  - Inheritance
  - Polymorphism

- Polymorphism is the ability to associate many meanings to one method name
  - It does this through a special mechanism known as *late binding* or *dynamic binding*

- A polymorphic method is one that has the same name for different classes of the same family, but has different implementations, or behavior, for the various classes.

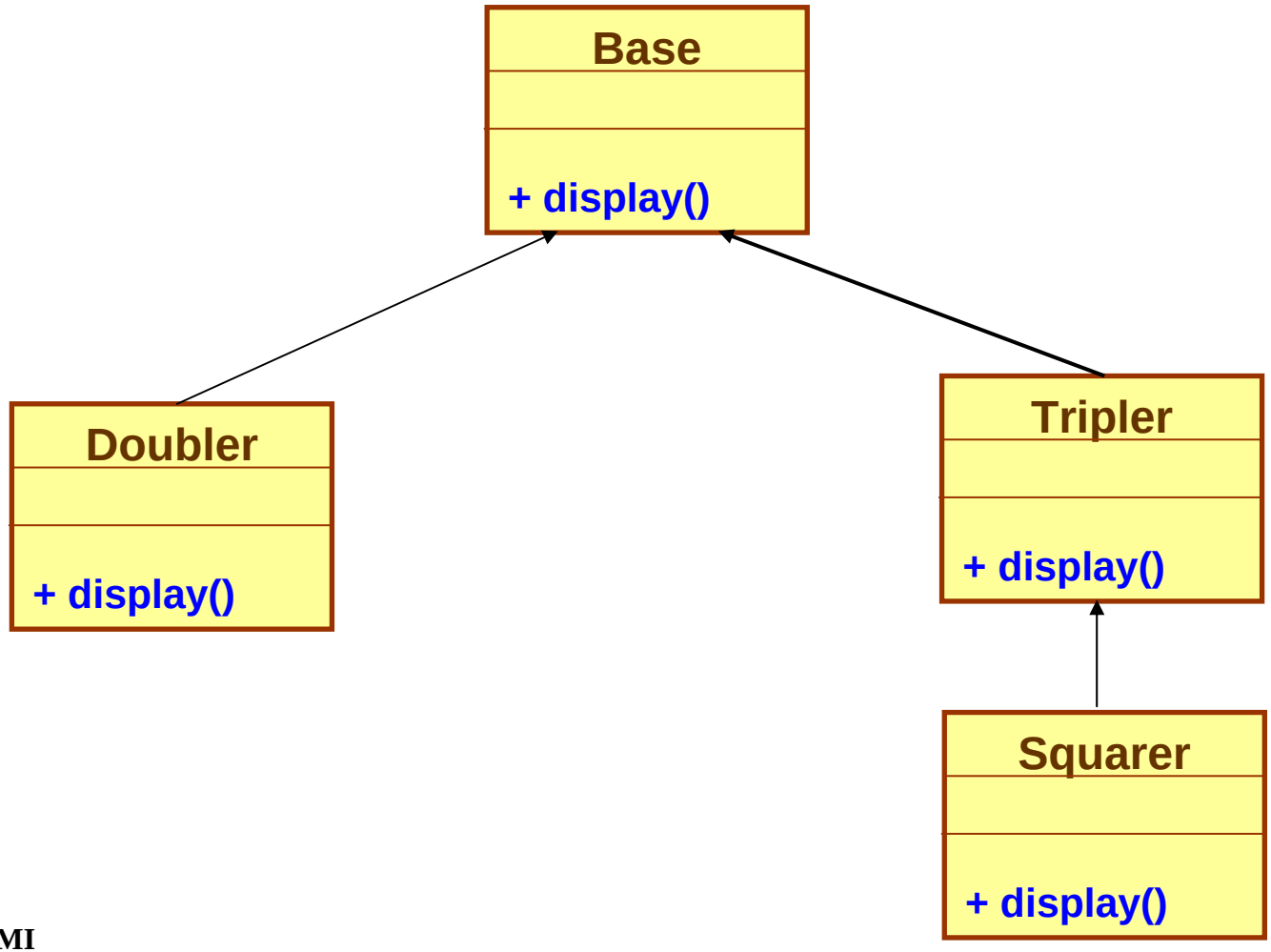
Introduction to Polymorphism

- **Polymorphism**
  - When a program invokes a method through a superclass variable, the correct subclass version of the method is called, based on the type of the reference stored in the superclass variable
  - The same method name and signature can cause different actions to occur, depending on the type of object on which the method is invoked
  - Facilitates adding new classes to a system with minimal modifications to the system's code

Example: Demonstrating Polymorphic Behavior

A polymorphic method (ex: display())

- **A method that has multiple meanings**
- **Created when a subclass overrides a method of the superclass**



Example: Demonstrating Polymorphic Behavior

```
public class Base {
   protected int i = 100;

   ...
   public void display() {    System.out.println( i );
   } }
```

```
public class Doubler extends Base {
   ...
   public void display() {System.out.println( i*2 );
   } }
```

```
public class Tripler extends Base {
   ...
   public void display() {
      System.out.println(i*3 );
   }  }
```

```
public class Squarer extends Tripler {
    ...
    public void display() {System.out.println( i*i );
    }  }
```

Example: Demonstrating Polymorphic Behavior

Case: Static binding

Some main program **output**

```
Base  B = new Base();
B. display();                    → 100

Doubler D = new Doubler();
D. display();                    → 200

Tripler T = new Tripler();
T. display();                    → 300

Squarer S = new Squarer();
S. display();                    → 10000
```

Static binding occurs when a method is defined with the same name but with different headers and implementations. The actual code for the method is attached, or bound, at compile time. Static binding is used to support overloaded methods in Java.

Example: Demonstrating Polymorphic Behavior
Case: Dynamic binding

- A superclass reference can be aimed at a subclass object
  - This is possible because a subclass object *is a* superclass object as well
  - When invoking a method from that reference, the type of the actual referenced object, not the type of the reference, determines which method is called

Some main program

output

```
Base  B = new Base();
B. display();
```
→ 100

```
Base D;
D = new Doubler();
D. display();
```
→ 200

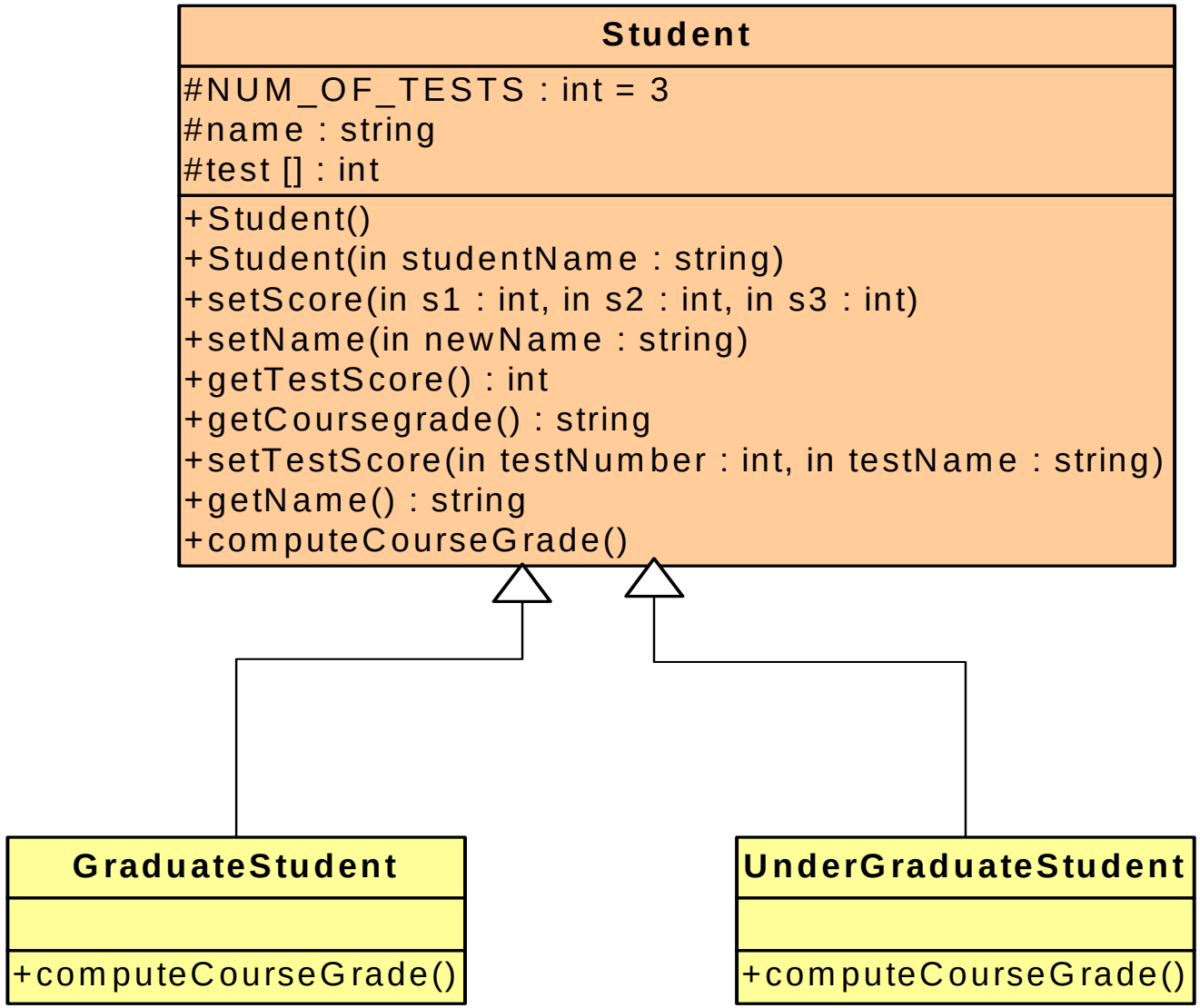
```
Base T;
T = new Tripler();
T. display();
```
→ 300

```
Base S;
S = new Squarer();
S. display();
```
→ 10000

Late binding or dynamic binding :

The appropriate version of a polymorphic method is decided at execution time

Example: Inheritance Hierarchy of Class Student : Polymorphism case



Example: Inheritance Hierarchy of Class Student : Polymorphism case

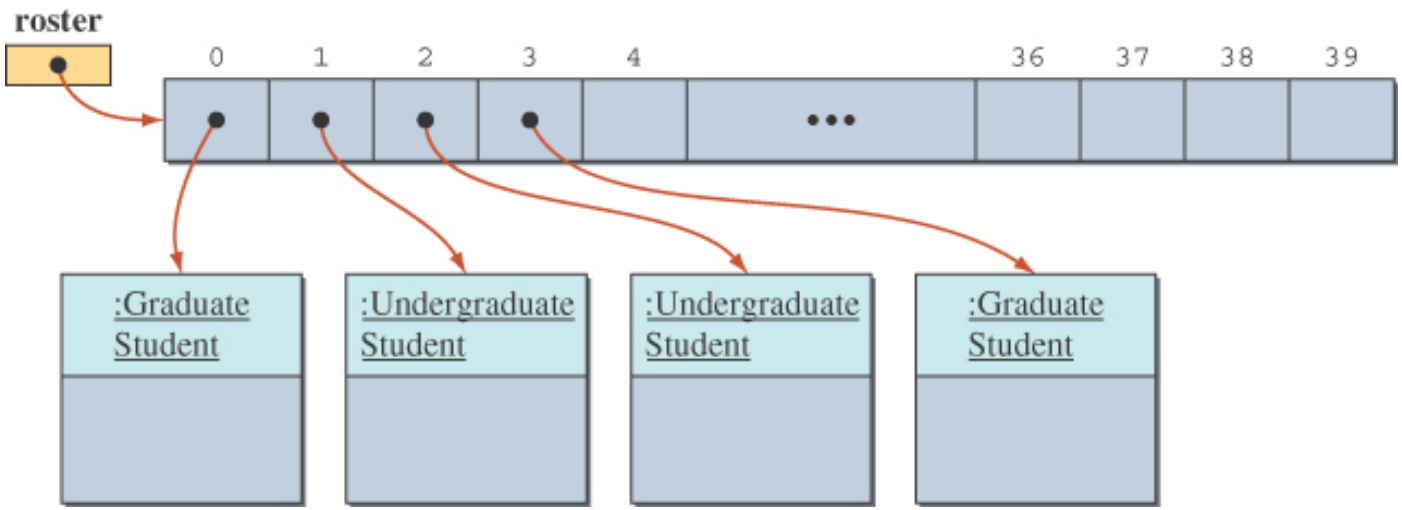
Creating the roster Array

- We mentioned in array definition that an array must contain elements of the same data type. For example, we can't store integers and real numbers in the same array.
- To follow this rule, it seems necessary for us to declare two separate arrays, one for graduate and another for undergraduate students. This rule, however, does not apply when the array elements are objects using the polymorphism. We only need to declare a single array.
- We can create the roster array combining objects from the **Student**, **UndergraduateStudent**, and **GraduateStudent** classes.

```
Student roster = new Student[40];
. . .
roster[0] = new GraduateStudent();
roster[1] = new UndergraduateStudent();
roster[2] = new UndergraduateStudent();
. . .
```

State of the roster Array

- The roster array with elements referring to instances of **GraduateStudent** or **UndergraduateStudent** classes.



Sample Polymorphic Message

- To compute the course grade using the roster array, we execute

```
for (int i = 0; i < numberOfStudents; i++) {
    roster[i].computeCourseGrade();
}
```

- If roster[i] refers to a GraduateStudent, then the computeCourseGrade method of the GraduateStudent class is executed.

- If roster[i] refers to an UndergraduateStudent, then the computeCourseGrade method of the UndergraduateStudent class is executed.

The instanceof Operator

- The instanceof operator can help us learn the class of an object.
- The following code counts the number of undergraduate students.

```
int undergradCount = 0;
for (int i = 0; i < numberOfStudents; i++) {
    if ( roster[i] instanceof UndergraduateStudent ) {
        undergradCount++;
    }
}
```

Implementation *Student* in Java

Case Study :

```
class Student {
   protected   final static int NUM_OF_TESTS = 3;
   protected   String          name;
   protected   int[]           test;
   protected   String          courseGrade;
   public Student( ) { this ("No Name"); }
   public Student(String studentName) {
      name = studentName;
      test = new int[NUM_OF_TESTS];
      courseGrade = "****";
   }
  public void setScore(int s1, int s2, int s3) {
      test[0] = s1; test[1] = s2; test[2] = s3;
   }
  public void computeCourseGrade() { courseGrade="";}

  public String getCourseGrade( ) {
    return courseGrade;    }
  public String getName( ) { return name; }
  public int getTestScore(int testNumber) {
    return test[testNumber-1];  }
  public void setName(String newName) {
    name = newName;  }
 public void setTestScore(int testNumber, int testScore)
  {              test[testNumber-1]=testScore;  }
 }
```

```
class GraduateStudent extends Student
{
  /**
     * students. Pass if total >= 80; otherwise, No Pass.
  */
   public void computeCourseGrade() {
      int total = 0;
      for (int i = 0; i < NUM_OF_TESTS; i++) {
        total += test[i]; }
      if (total >= 80) {
        courseGrade = "Pass";
      } else { courseGrade = "No Pass";  }
   }
}
```

```
class UnderGraduateStudent extends Student {

   public void computeCourseGrade() {
     int total = 0;
     for (int i = 0; i < NUM_OF_TESTS; i++) {
       total += test[i]; }
     if (total >= 70) {
       courseGrade = "Pass";
     } else {   courseGrade = "No Pass";  }
   }
}
```

Implementation *StudentTest* in Java

Case Study :

```
public class StudentTest  {
  public static void main(String[] args)
  {
     Student roster[]= new Student[2];
      roster[0] = new  GraduateStudent();
      roster[1] = new  UnderGraduateStudent();

      roster[0].setScore (20, 30, 50);
       roster[1].setScore (10, 17, 13);

      for (int i=0; i<roster.length; i++)
      {
        System.out.println("The name of the class is : " +  roster[i].getClass().getName());
        roster[i].computeCourseGrade();
         System.out.println(" Pass or Not  : " + roster[i].getCourseGrade());
      }
   }
}
```

```
------ execution------------------
The name of the class is : GraduateStudent
 Pass or Not  : Pass
The name of the class is : UnderGraduateStudent
 Pass or Not  : No Pass
```

If roster[i] refers to a GraduateStudent, then the computeCourseGrade method of the GraduateStudent class is executed.

If roster[i] refers to a UnderGraduateStudent, then the computeCourseGrade method of the UnderGraduateStudent class is executed.

We call the message computeCourseGrade *polymorphic*

Implementation *StudentTest2* in Java

Case Study : **Question: Count the number of under graduate students**

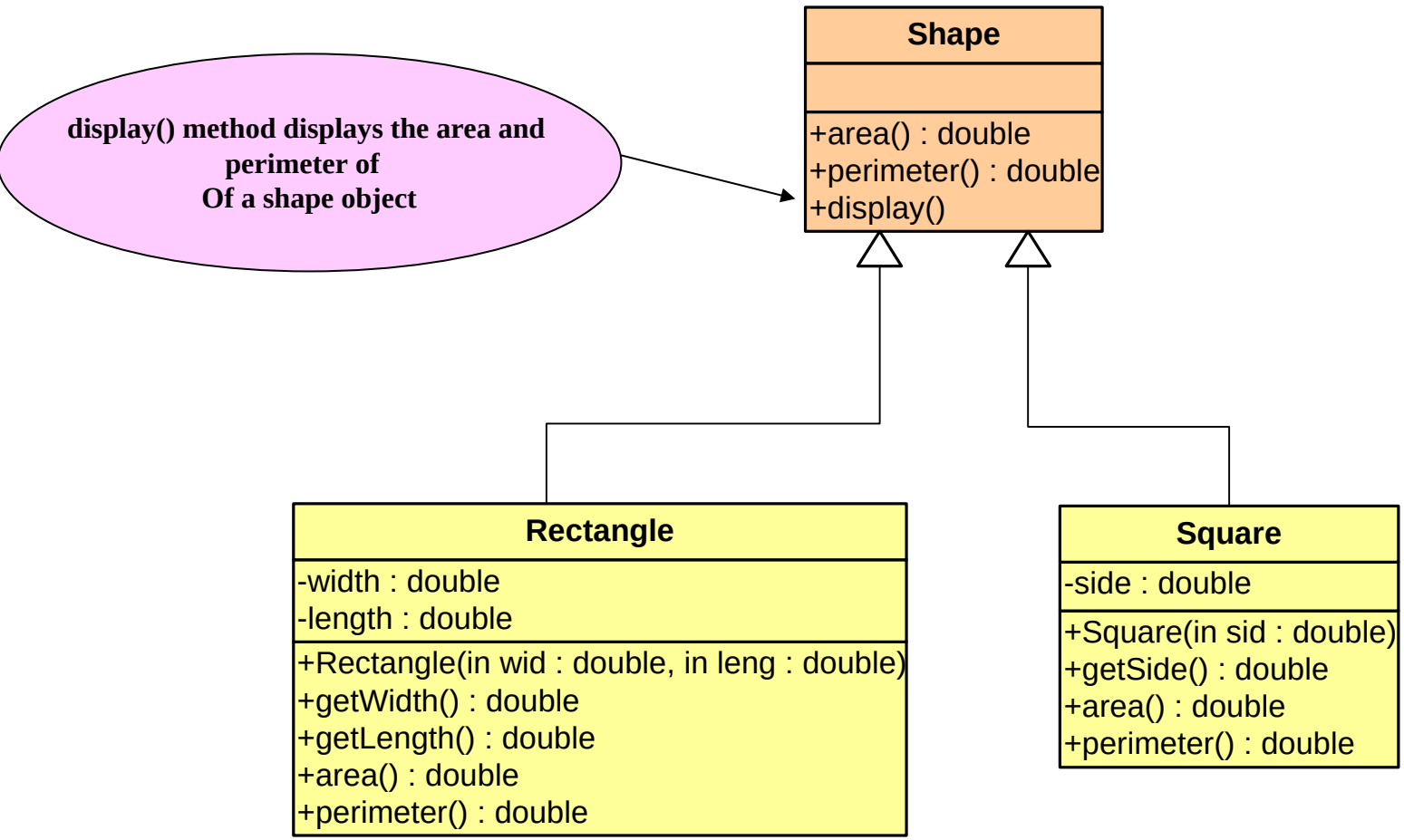
```
public class StudentTest2  {
  public static void main(String[] args)
  {
     Student roster[]= new Student[2];
      roster[0] = new  GraduateStudent();
      roster[1] = new  UnderGraduateStudent();

      roster[0].setScore (20, 30, 50);
       roster[1].setScore (10, 17, 13);
     int nb=0;   //=== count the number of Under Graduate Students
     for (int i=0; i<roster.length; i++)
        if (roster[I] instanceof UnderGraduateStudent )
              nb++;

        System.out.println("The number of Under Graduate Students : " + nb);
     }       }  }
```

------ execution----------

The number of Under Graduate Students : 1

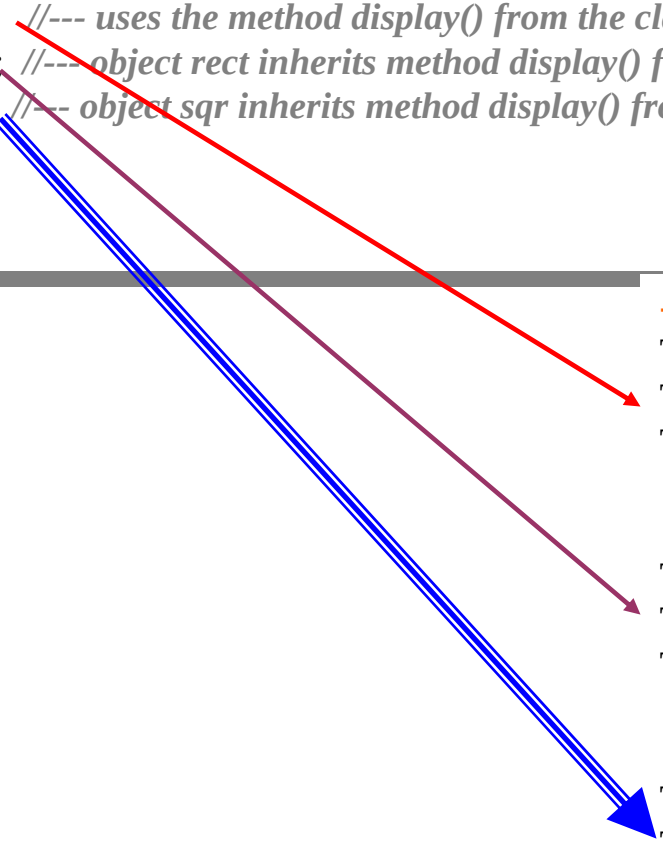
Rule: To Determine the class of an object , we use the *instanceof* operator.

Example: Inheritance Hierarchy of Class Shape



Test: inheritance of Super-Class Shape

```
public class ShapeTest {
    public static void main(String[] args)
    {
            Shape shp =new Shape();  // shp is an object from class Shape
            Rectangle  rect =new Rectangle(4.0, 5.0);  // rect is an object from class Rectangle
            Square sqr = new Square(6.0);  // sqr is an object from class Square

            shp.display();  //--- uses the method display() from the class Shape
            rect.display();  //--- object rect inherits method display() from Superclass Shape
            sqr.display();  //--- object sqr inherits method display() from Superclass Shape
}
}
```



---- execution --------

The name of the class is : Shape
The area is :0.0
The perimeter is :0.0

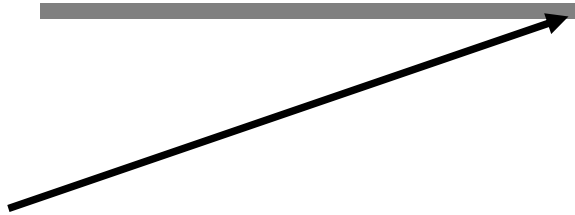
The name of the class is : Rectangle
The area is :20.0
The perimeter is :13.0

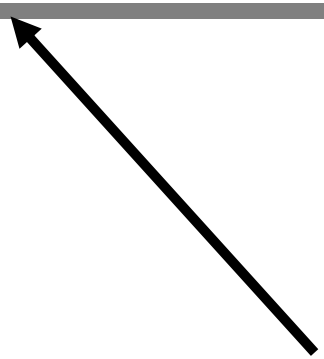
The name of the class is : Square
The area is :36.0
The perimeter is :24.0

Implementation inheritance in Java

Case Study 3: Shape

```
public class Shape  {
    public double area()    {  return 0.0;  }
    public double perimeter() { return 0.0;};
    public void display()  {
     System.out.println("The name of the class is : " +  this.getClass().getName());
      //--- getClass() a method inherits from the super class Object.
      //--- getName() a method from the class String.
      System.out.println("The area is :"+ area());
      System.out.println("The perimeter is :"+ perimeter()+"\n\n");}
}
```



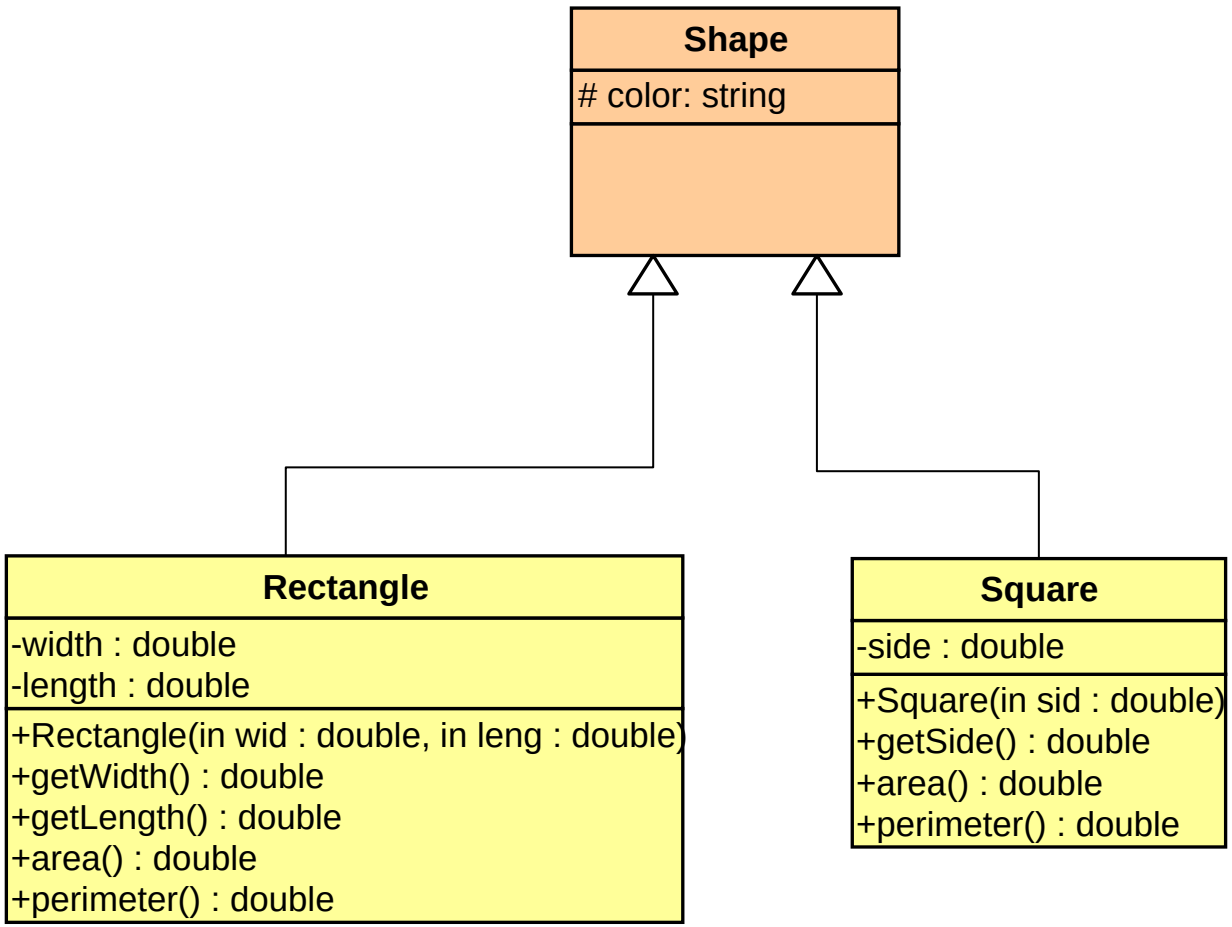


```
public class Rectangle extends Shape {
   private double width;
   private double length;
   public Rectangle(double length, double width)
   {   this.length = length;    this.width = width;
    }
public double getLength() {return length; }
public double getWidth()  {return width; }
 public double area(){
    return (this.getLength()*this.getWidth());
  }
 public double perimeter(){
    return (2*this.getLength()+this.getWidth()); }}
```

```
public class Square extends Shape  {
   private double side;
   public Square(double side) {  this.side = side; }
   public double getSide() {          return side;          }
   public double area() {
        return (this.getSide()*this.getSide());
    }
    public double perimeter() {
                return (4*this.getSide());

    }}
```

Introduction to Abstract Classes

In the following example, we want to add to the Shape class a **display** method that prints the area and perimeter of a shape.



Introduction to Abstract Classes

Abstract Method

- The following method is added to the **Shape** class

```
public void display()
{
  System.out.println (this.area());
  System.out.println (this.perimeter());

}
```

Introduction to Abstract Classes

Abstract Method

- There are several problems with this method:
  - The **`area`** and **`perimeter`** methods are invoked in the **`display`** method
  - There are **`area`** and **`perimeter`** methods in each of the subclasses
  - There is no **`area`** and **`perimeter`** methods in the **`Shape`** class, nor is there any way to define it reasonably without knowing whether the shape is Rectangle or Square.

Introduction to Abstract Classes

Abstract Class

- In order to postpone the definition of a method, Java allows an *abstract method* to be declared
  - An abstract method has a heading, but no method body
  - The body of the method is defined in the subclasses
- **The class that contains an abstract method is called an *abstract class***

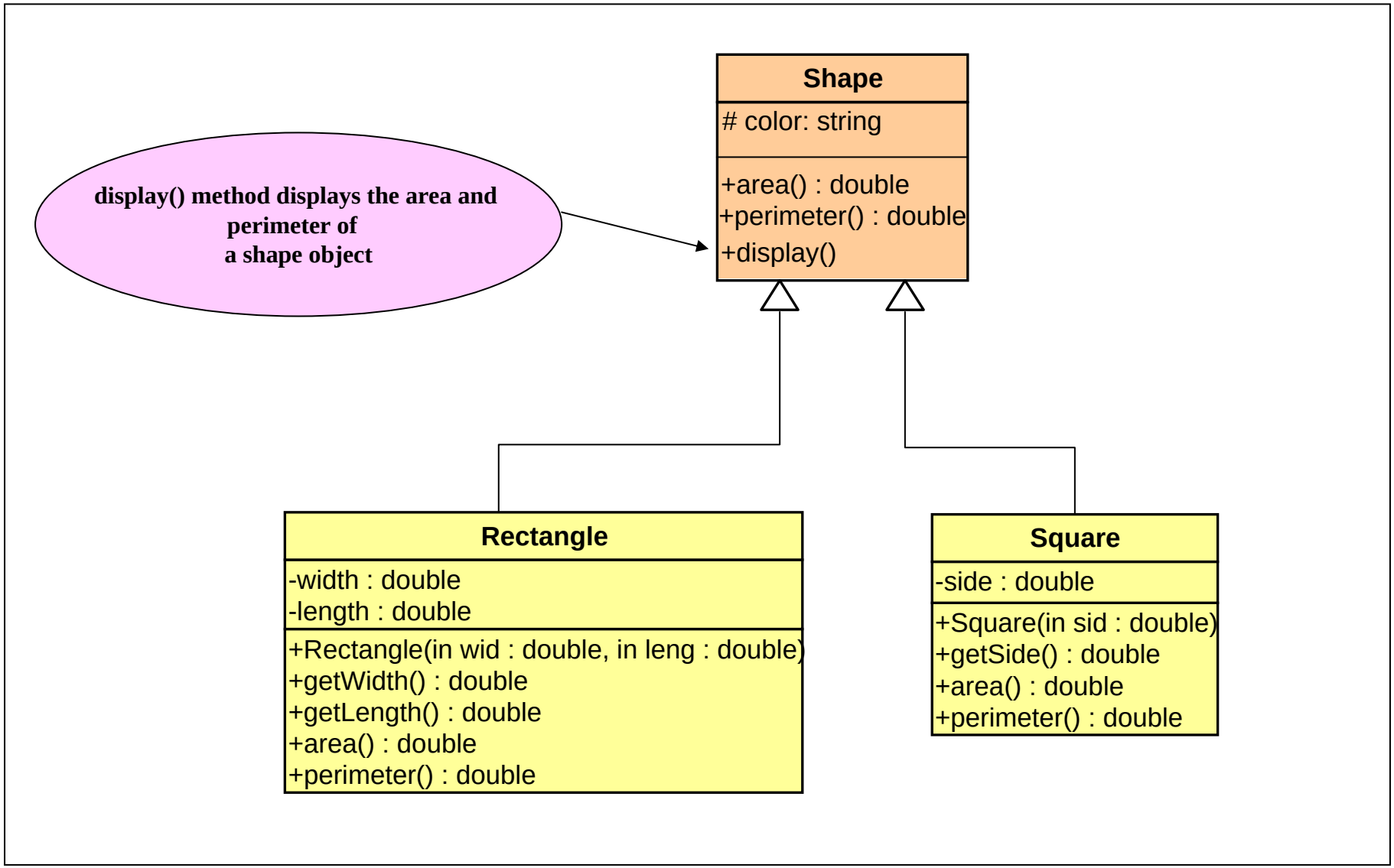
Introduction to Abstract Classes

Abstract Method

- An abstract method is like a **placeholder** for a method that will be fully defined in a descendent class
- It has a complete method heading, to which has been added the modifier **abstract**
- **It cannot be private**
- It has **no method body**, and ends with a semicolon in place of its body

```
public abstract double area();
public abstract double perimeter();
```

Introduction to Abstract Classes



Introduction to Abstract Classes

- A class that has at least one abstract method is called an *abstract class*
  - An abstract class must have the modifier **`abstract`** included in its class heading:

```
public abstract class Shape
{
  protected String color;
  . . .
  public abstract double area();
  public abstract double perimeter();
  public void display()
  {
    System.out.println (this.area());
    System.out.println (this.perimeter());
  }
  . . .
}
```

Introduction to Abstract Classes

- An abstract class can have any number of abstract and/or fully defined methods

- If a derived class of an abstract class adds to or does not define all of the abstract methods, then it is abstract also, and must add **`abstract`** to its modifier

- A class that has no abstract methods is called a *concrete class*

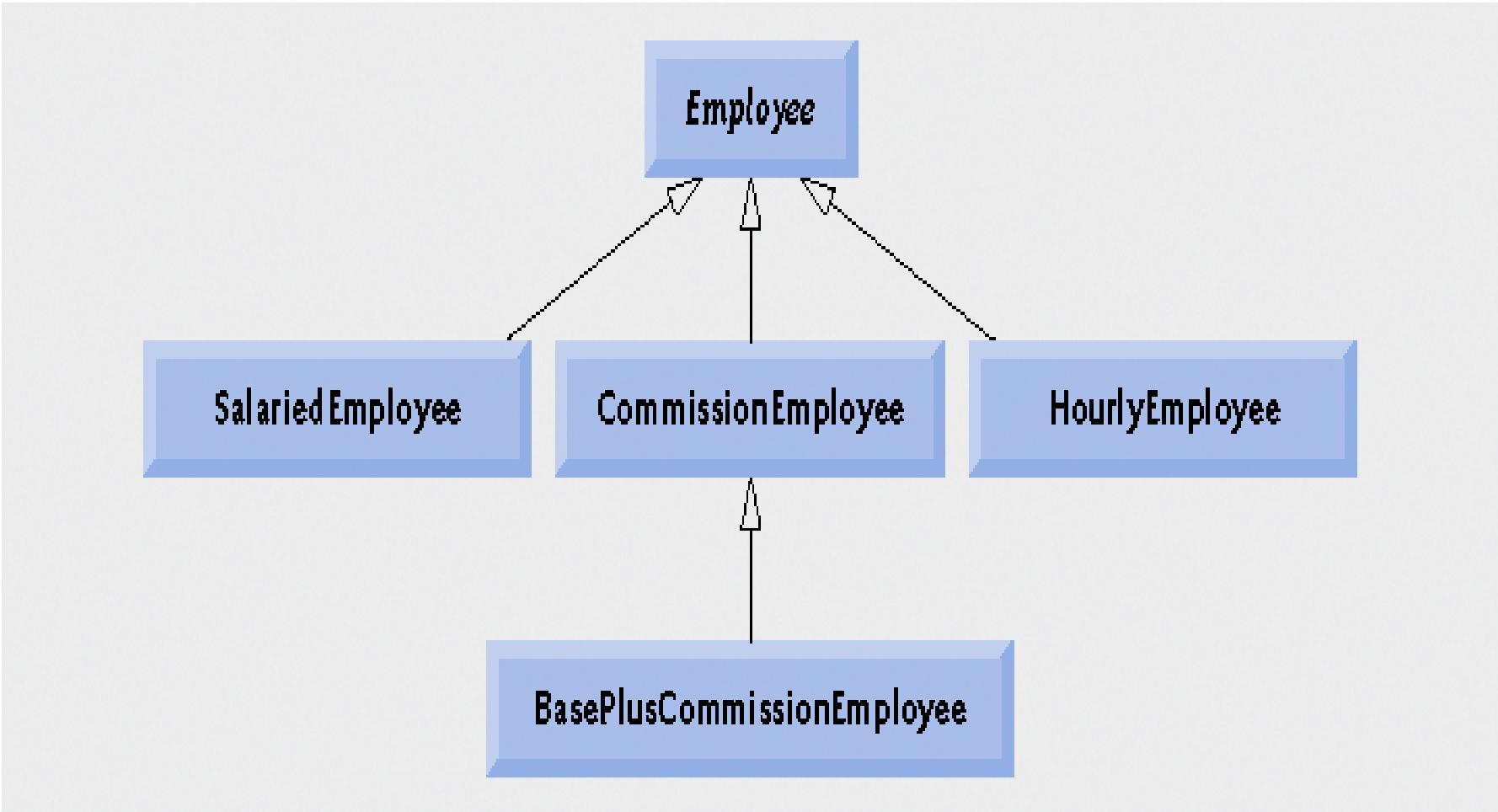
Pitfall: You Cannot Create Instances of an Abstract Class

- An abstract class can only be used to derive more specialized classes
  - While it may be useful to discuss shape in general, in reality a shape must be a rectangle form or a square form
- An abstract class constructor cannot be used to create an object of the abstract class
  - However, a subclass constructor will include an invocation of the abstract class constructor in the form of **`super`**

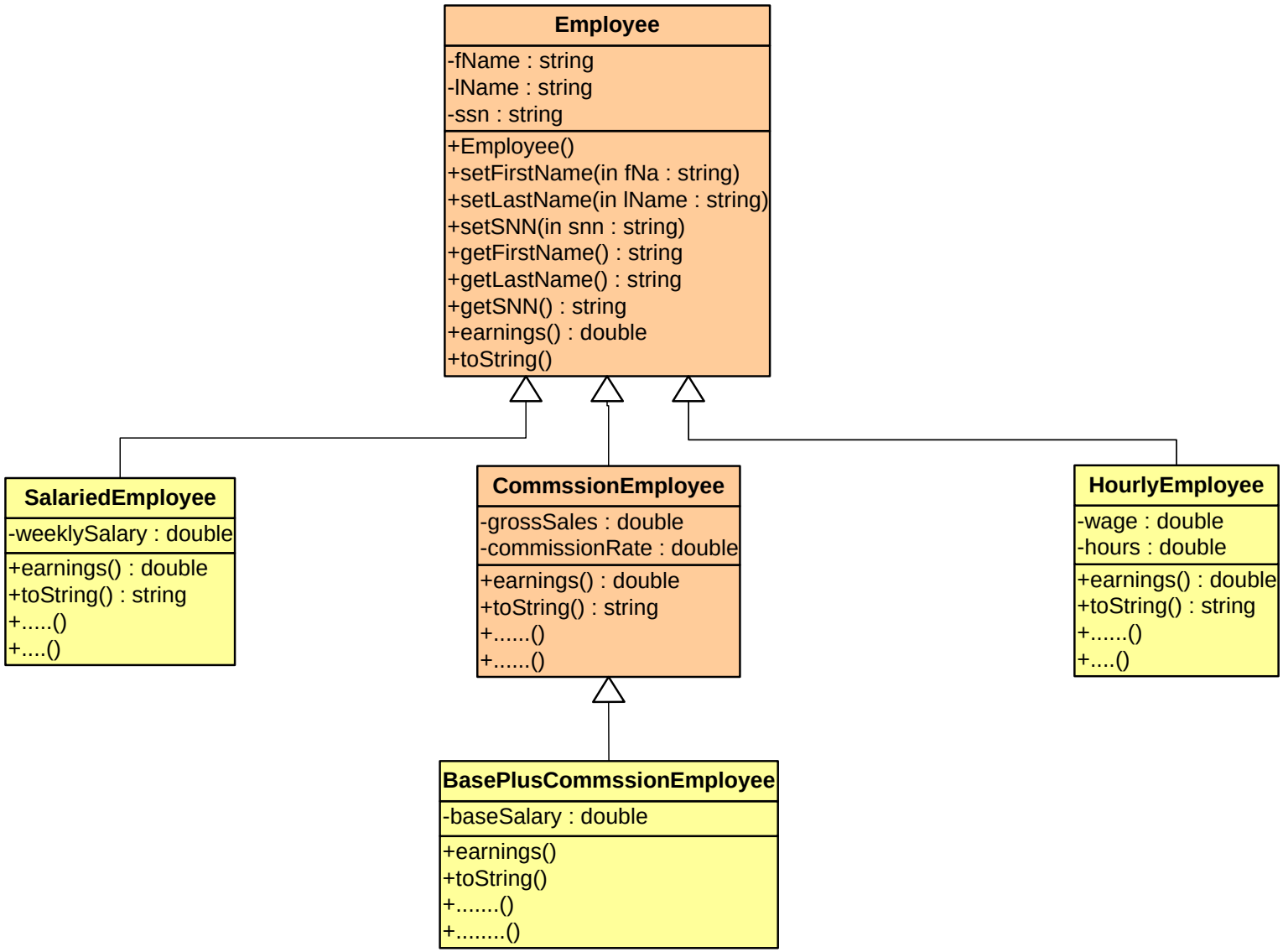
Dynamic Binding and Abstract Classes

- Controlling whether a subclass can override a superclass method
  - Field modifier `final`
    - Prevents a method from being overridden by a subclass
  - Field modifier `abstract`
    - Requires the subclass to override the method
- Early binding or static binding
  - The appropriate version of a method is decided at compilation time
  - Used by methods that are `final` or `static`

`Employee` hierarchy UML class diagram.



Example: Inheritance Hierarchy of Class Employee



Implementation *Employee* in Java

Case Study :

```
public abstract class Employee
{
   private String firstName;
   private String lastName;
   private String socialSecurityNumber;

   // three-argument constructor
public Employee( String first, String last, String ssn
)
   {    firstName = first;    lastName = last;
      socialSecurityNumber = ssn;
   } // end three-argument Employee constructor

   // set first name
   public void setFirstName( String first )
   {      firstName = first;
   } // end method setFirstName

   // return first name
   public String getFirstName()
   { return firstName;
   } // end method getFirstName
   // set last name
   public void setLastName( String last )
   {lastName = last;
   } // end method setLastName
```

```
// return last name
   public String getLastName()
   {
     return lastName;
   } // end method getLastName
   // set social security number
   public void setSocialSecurityNumber( String ssn )
   {  socialSecurityNumber = ssn; // should validate
   } // end method setSocialSecurityNumber

   // return social security number
   public String getSocialSecurityNumber()
   {  return socialSecurityNumber;
   } // end method getSocialSecurityNumber

   // return String representation of Employee object
   public String toString()
   {return ("The name is :"+ getFirstName()+" "+
getLastName() + "\nThe Social Security Number: "+
getSocialSecurityNumber() );
   } // end method toString

   // abstract method overridden by subclasses
   public abstract double earnings(); // no
implementation here
} // end abstract class Employee
```

Implementation *SalariedEmployee* in Java

Case Study :

```
public class SalariedEmployee extends Employee
{
   private double weeklySalary;
   // four-argument constructor
   public SalariedEmployee( String first, String last, String
ssn,   double salary )
   {
      //super( first, last, ssn ) code reuse
      super( first, last, ssn ); // pass to Employee constructor
      setWeeklySalary( salary ); // validate and store salary
   } // end four-argument SalariedEmployee constructor

   // set salary
   public void setWeeklySalary( double salary )
   {
      weeklySalary = salary < 0.0 ? 0.0 : salary;
// this mean that, if salary is <0 then put it 0 else put it salary
   } // end method setWeeklySalary

   // return salary
   public double getWeeklySalary()
   {      return weeklySalary;
   } // end method getWeeklySalary
```

```
// calculate earnings; override abstract method earnings
in Employee
   public double earnings()
   { return getWeeklySalary();
   } // end method earnings

   // return String representation of SalariedEmployee
object
   //  this method override toString() of superclass method
   public String toString()
   {     //***** super.toString() : code reuse (good
example)
         return ( super.toString()+ "\nearnings = " +
getWeeklySalary());
         } // end method toString
} // end class SalariedEmployee
```

Implementation *HourlyEmployee* in Java

Case Study :

```
public class HourlyEmployee extends Employee
{
  private double wage; // wage per hour
  private double hours; // hours worked for week
  // five-argument constructor
  public HourlyEmployee( String first, String last, String
ssn,    double hourlyWage, double hoursWorked )
  {
     //  super( first, last, ssn ) code (constructor) reuse
    super( first, last, ssn );
 setWage( hourlyWage ); // validate and store hourly wage
setHours( hoursWorked ); // validate and store hours
worked
  } // end five-argument HourlyEmployee constructor
  public void setWage( double hourlyWage )
  {    wage = ( hourlyWage < 0.0 ) ? 0.0 : hourlyWage;
  } // end method setWage
  public double getWage()
  { return wage;
  } // end method getWage
  public void setHours( double hoursWorked )
  {hours = ( ( hoursWorked >= 0.0 ) && ( hoursWorked <=
168.0 ) ) ?   hoursWorked : 0.0;
  } // end method setHours
  public double getHours()
  {      return hours;
  } // end method getHours
```

```
  // calculate earnings; override abstract method earnings
in Employee
  public double earnings()
  {
    if ( getHours() <= 40 ) // no overtime
      return getWage() * getHours();
    else
      return 40 * getWage() + ( getHours() - 40 ) *
getWage() * 1.5;
  } // end method earnings

  // return String representation of HourlyEmployee
object
  public String toString()  /* here overriding the
toString() superclass method */
  {   /*code reuse using super.   */
     return (super.toString() + "\nHourly wage: " +
getWage() +
      "\nHours worked :"+ getHours()+ "\nSalary is :
"+earnings() );
  } // end method toString
} // end class HourlyEmployee
```

Implementation *ComissionEmployee* in Java

Case Study :

```
public class CommissionEmployee extends Employee
{
   private double grossSales; // gross weekly sales
   private double commissionRate; // commission
percentage

   // five-argument constructor
   public CommissionEmployee( String first, String last,
String ssn,   double sales, double rate )
   {
      super( first, last, ssn );
      setGrossSales( sales );  setCommissionRate( rate );
   } // end five-argument CommissionEmployee constructor

   // set commission rate
   public void setCommissionRate( double rate )
   { commissionRate = ( rate > 0.0 && rate < 1.0 ) ? rate :
0.0;
   } // end method setCommissionRate

   // return commission rate
   public double getCommissionRate()
   {return commissionRate;
   } // end method getCommissionRate

   // set gross sales amount
   public void setGrossSales( double sales )
   { grossSales = ( sales < 0.0 ) ? 0.0 : sales;
   } // end method setGrossSales

   // return gross sales amount
   public double getGrossSales()
   { return grossSales;
   } // end method getGrossSales

   // calculate earnings; override abstract method earnings
in Employee
   public double earnings()
   { return getCommissionRate() * getGrossSales();
   } // end method earnings

   // return String representation of
CommissionEmployee object
   public String toString()
   { return (super.toString() + "\nGross sales: " +
getGrossSales() +  "\nCommission rate: " +
getCommissionRate() + "\nearnings = " + earnings() );
   } // end method toString
} // end class CommissionEmployee
```

Implementation *BasePlusComissionEmployee* in Java

Case Study :

```
public class BasePlusCommissionEmployee extends
CommissionEmployee
{
  private double baseSalary; // base salary per week

  // six-argument constructor
  public BasePlusCommissionEmployee( String first,
String last,  String ssn, double sales, double rate, double
salary ) {
    super( first, last, ssn, sales, rate );
    setBaseSalary( salary ); // validate and store base salary
  } // end six-argument BasePlusCommissionEmployee
constructor

  // set base salary
  public void setBaseSalary( double salary )
  {
    baseSalary = ( salary < 0.0 ) ? 0.0 : salary; // non-
negative
  } // end method setBaseSalary

  // return base salary
  public double getBaseSalary()
  {
    return baseSalary;
  } // end method getBaseSalary
```

```
// calculate earnings; override method earnings in
CommissionEmployee
  public double earnings()
  {
    return getBaseSalary() + super.earnings(); //code
reuse form CommissionEmployee
  } // end method earnings

  // return String representation of
BasePlusCommissionEmployee object
  public String toString()
  {
    return ( "\nBase-salaried :" + super.toString() +
    "\nBase salary: " + getBaseSalary() + "\nearnings ="
+ earnings() );
  }// end method toString
} // end class BasePlusCommissionEmployee
```

Implementation PayrollSystemTest in Java

```
public class PayrollSystemTest
{
   public static void main( String args[] )
   {
      // create subclass objects
  SalariedEmployee SA=  new SalariedEmployee( “Ali", "Samer", "111-11-1111", 800.00 );
  HourlyEmployee HE =   new HourlyEmployee( “Ramzi", “Ibrahim", "222-22-2222", 16.75, 40 );
  CommissionEmployee CE =  new CommissionEmployee(  “Med", “Ahmed", "333-33-3333", 10000, .06 );
 BasePlusCommissionEmployee BP = new BasePlusCommissionEmployee(“Beji", “Lotfi", "444-44-4444", 5000, .04, 300 );

  System.out.println( "Employees processed individually:\n" );
     /*  salariedEmployee is the same as salariedEmployee.toString()  */
  System.out.println( SA.toString()+ "\nearned: " + SA.earnings()+"\n\n" );
  System.out.println( HE + "\n earned: " + HE.earnings()+"\n\n" );
  System.out.println(CE + "\n earned: " + CE.earnings()+"\n\n" );
  System.out.println(BP + "\n earned: "+ BP.earnings()+"\n\n" );
// create four-element Employee array
  Employee employees[] = new Employee[ 4 ];
  employees[ 0 ] = SA;   employees[ 1 ] = HE;  employees[ 2 ] = CE;   employees[ 3 ] = BP;
  System.out.println( "Employees processed polymorphically:\n" );
// generically process each element in array employees
  for (Employee currentEmployee : employees)        {
    System.out.println( currentEmployee );} // invokes toString  : here is polymorphysim : call toString() of class at the executiontime.
                                                 //  called dynamic binding or late binding
                                                 // Note :only methods of superclass  can be called via superclass variable
 // get type name of each object in employees array
  for ( int j = 0; j < employees.length; j++ )
    System.out.printf( "Employee %d is a %s\n", j,   employees[ j ].getClass().getName() );  // display the name of the class whos
                                                                                              //object is employee[j]
   } // end main     } // end class PayrollSystemTest
```