Chapter 11: Inheritance

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Objectives

- Inheritance (继承)
- Superclass (父类) and subclass (子类)
- The `protected` keyword
- Overriding (重写)

A Motivating Example

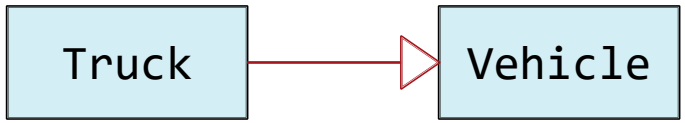
- Consider a scenario where you have carefully designed and implemented a `Vehicle` class, and you need a `Truck` class in your system. Will you create the new class from scratch?

On one hand, trucks have some traits in common with many vehicles. Some code can be shared (So no?)

On another hand, trucks have their own characteristics, e.g., two seats, can carry huge things (So yes?)

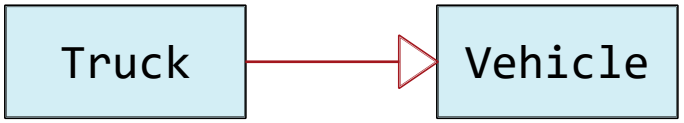
Inheritance (继承)

- Rather than declaring completely new members, you can designate that the new class should inherit the members of an existing class.
  - Vehicle class is the superclass (base class, parent class)
  - Truck class is the subclass (derived class, child class)



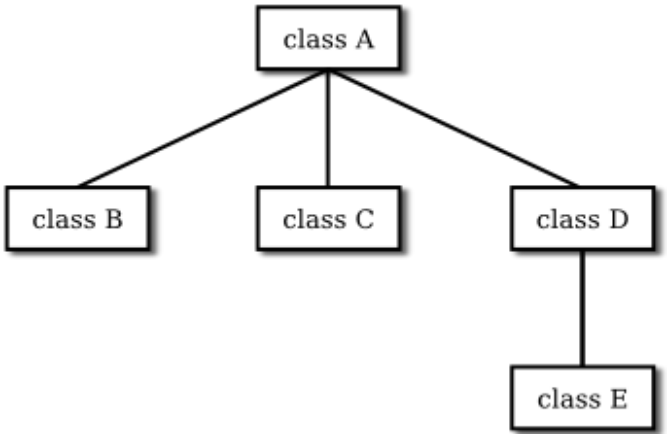
Superclass & Subclass

- A subclass inherits the fields and methods of its superclass
- A subclass can add its own fields and methods.
- Reusability: The subclass exhibits/reuses the behaviors of its superclass and can add new behaviors that are specific to the subclass.
  - This is why inheritance is sometimes referred to as specialization (特殊化).



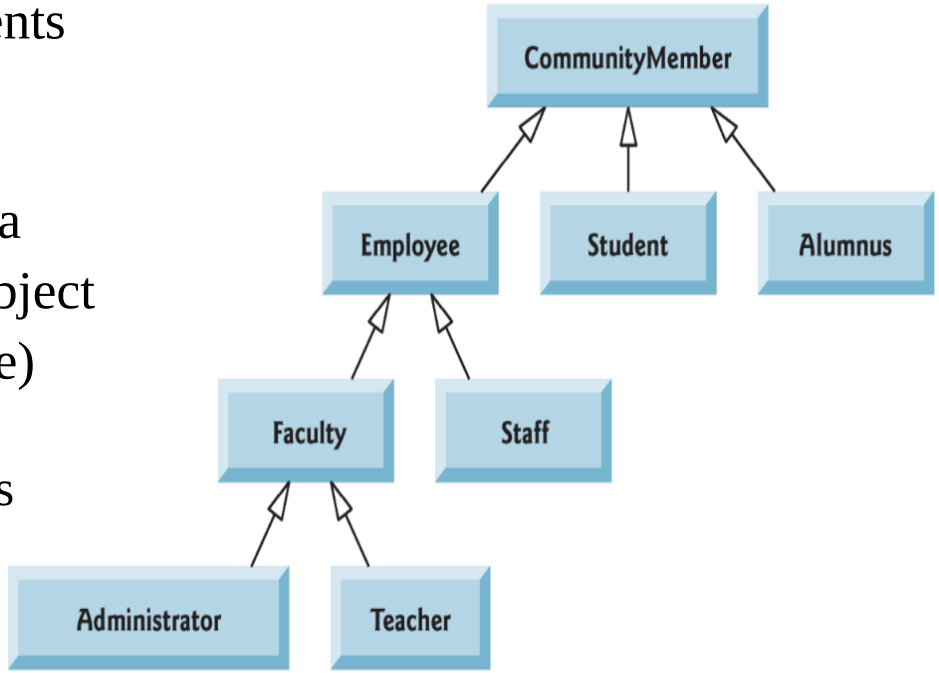
Class Hierarchy

- Each subclass can be a superclass of future subclasses, forming a class hierarchy (类层次结构)
- The direct superclass is the superclass from which the subclass explicitly inherits (`A` is the direct superclass of `C`)
- An indirect superclass is any class above the direct superclass in the class hierarchy (e.g., `A` is an indirect superclass of `E`)



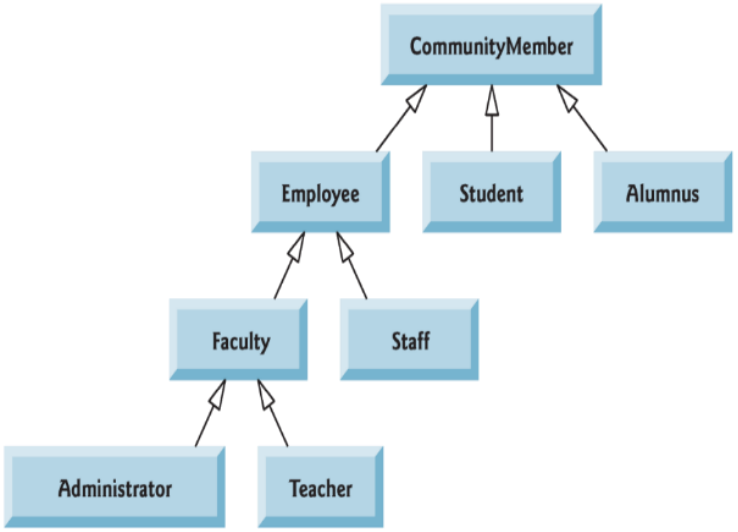
Class Hierarchy

- Each arrow in the hierarchy represents an *is-a relationship*.
- In an is-a relationship, an object of a subclass can also be treated as an object of its superclass (a truck **is a** vehicle)
- Follow the arrows upward in the class hierarchy
  - a `Teacher` **is a** `Faculty` (also an `Employee`, a `CommunityMember`)

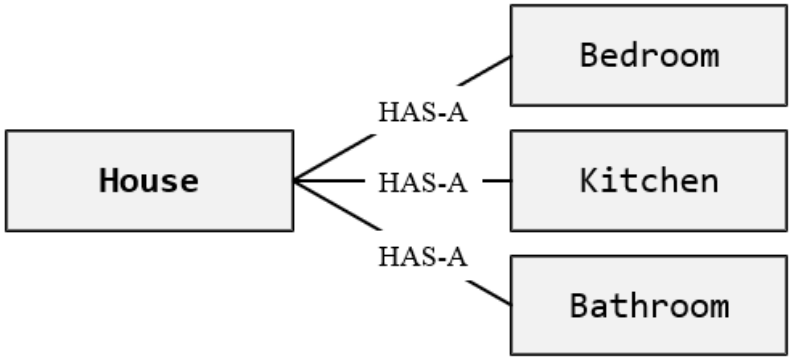


Inheritance vs. Composition

- **Inheritance:** *Is-a* relationship between classes
  - In an *is-a* relationship, an object of a subclass can also be treated as an object of its superclass (a truck is also a vehicle)

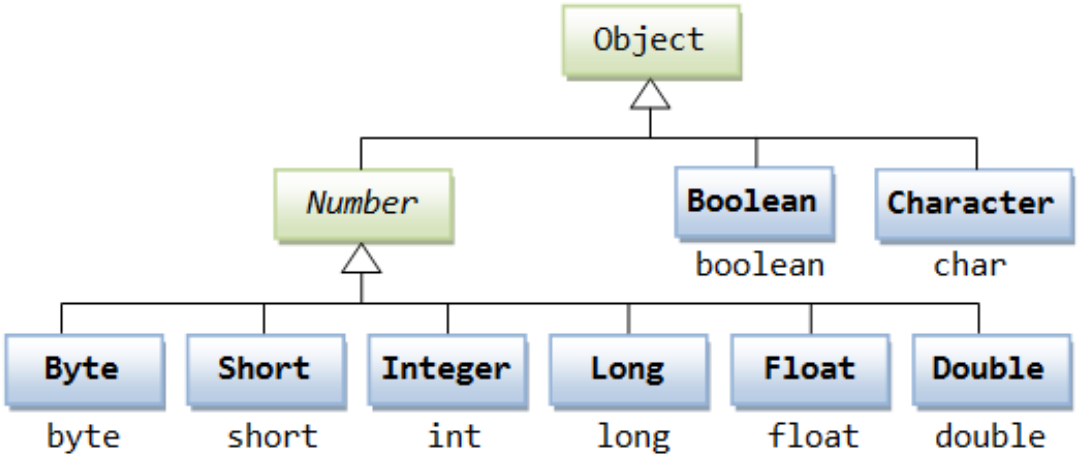


- **Composition:** *Has-a* relationship between classes
  - In a *has-a* relationship, an object contains references to other objects as members (a house contains a kitchen)



Class Hierarchy

- The Java class hierarchy begins with class `java.lang.Object`
  - *Every* class directly or indirectly extends (or "inherits from") `Object`.
- Java supports only single inheritance, in which each class is derived from exactly one direct superclass.



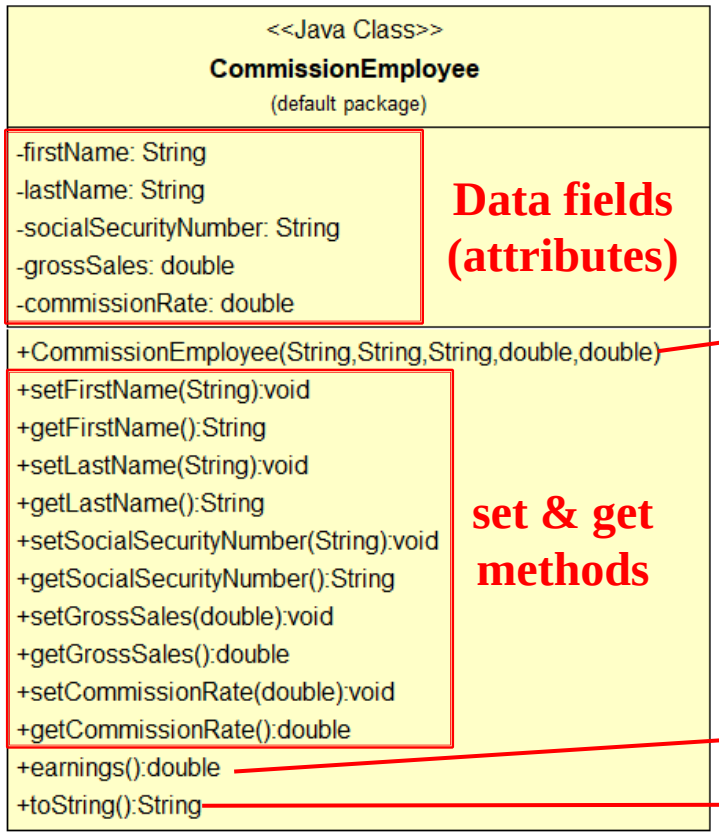
Objects of all classes that extend a common superclass can be treated as objects of that superclass (e.g., `java.lang.Object`)

Case Study: A Payroll Application
(工资表应用程序)

- Suppose we need to create classes for two types of employees
  - Commission employees (佣金员工) are paid a percentage of their sales (`ComissionEmployee`)
  - Base-salaried commission employees (持底薪佣金员工) receive a base salary plus a percentage of their sales (`BasePlusCommissionEmployee`)

Design Choice #1

- Creating the two classes independently



A five-argument constructor

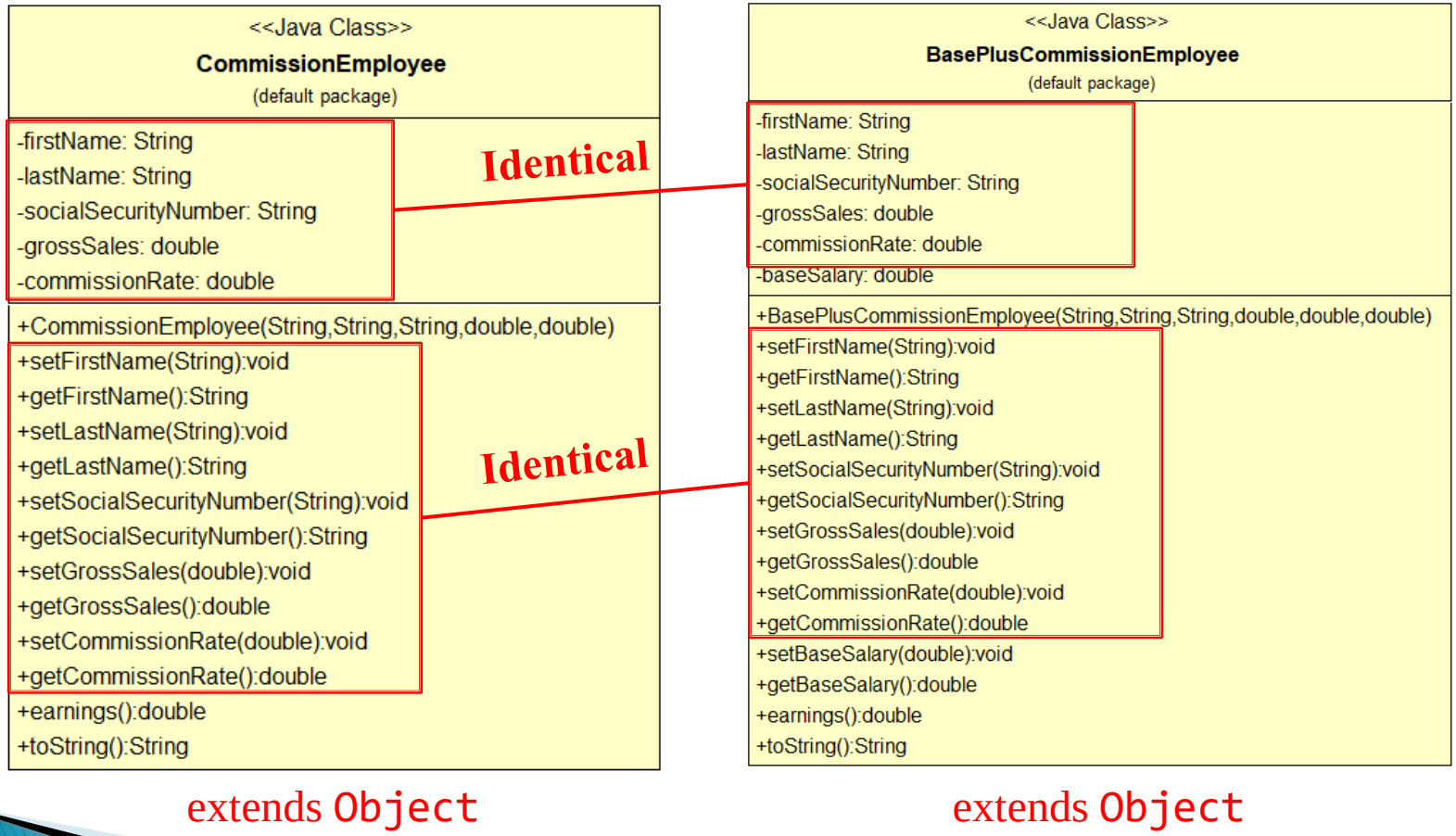
Earning calculation method

Transform object to string representation

extends `Object`

Design Choice #1

- Creating the two classes independently



Problems of Design Choice #1

- Much of `BasePlusCommissionEmployee`'s code will be identical to that of `CommissionEmployee`

- For implementation, we will literally copy the code of the class `CommissionEmployee` and paste the copied code into the class `BasePlusCommissionEmployee`
  - "Copy-and-paste" approach is often error prone. It spreads copies of the same code throughout a system, creating code-maintenance nightmares

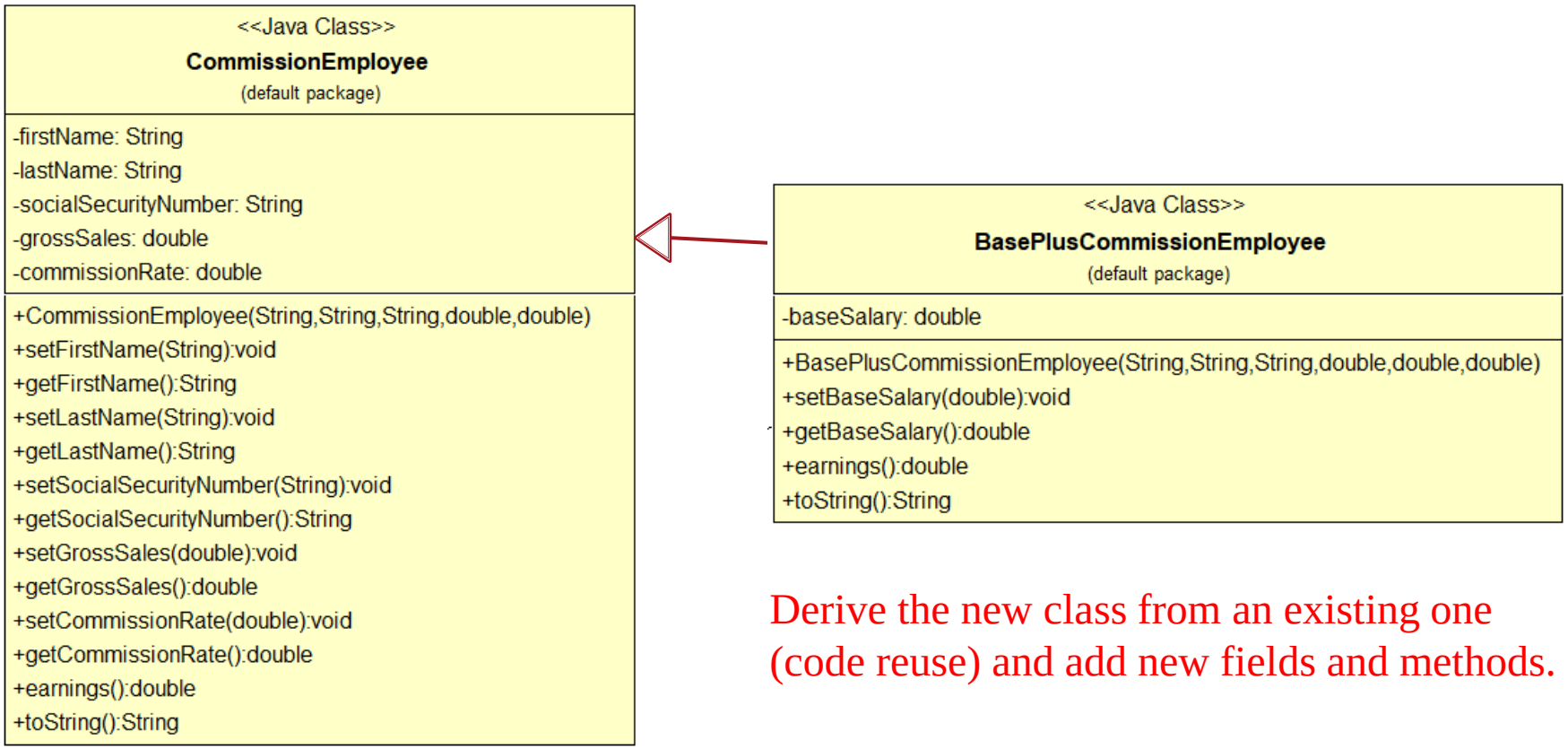
Comparing the Two Types

- **Commonalities**
  - Both classes need data fields to store the employee's personal information (e.g., name, social security number)

- **Differences**
  - `BasePlusCommissionEmployee` class needs one additional field to store the employee's base salary
  - The way of calculating the earnings are different

Design Choice #2

- `BasePlusCommissionEmployee` extends `CommissionEmployee`



extends `Object`

Derive the new class from an existing one (code reuse) and add new fields and methods.

CommissionEmployee

```
public class CommissionEmployee extends Object {
    private String firstName;
    private String lastName;
    private String socialSecurityNumber;
    private double grossSales;
    private double commissionRate;
    ...
```

"`extends Object`" is optional. If you don't explicitly specify which class a new class extends, the class extends `Object` implicitly.

CommissionEmployee

A five-argument constructor

```
public CommissionEmployee(String first, String last, String ssn,
                          double sales, double rate) {
    firstName = first;
    lastName = last;
    socialSecurityNumber = ssn;
    setGrossSales(sales); // data validation
    setCommissionRate(rate); // data validation
}
public void setGrossSales(double sales) {
    grossSales = (sales < 0.0) ? 0.0 : sales;
}
public void setCommissionRate(double rate) {
    commissionRate = (rate > 0.0 && rate < 1.0) ? rate : 0.0;
}
```

CommissionEmployee

Several other get and set methods

```
public void setFirstName(String first) {  firstName = first;  }
public String getFirstName() {  return firstName;  }
public void setLastName(String last) {  lastName = last;  }
public String getLastName() {  return lastName;  }
public void setSocialSecurityNumber(String ssn) { socialSecurityNumber = ssn; }
public String getSocialSecurityNumber() {  return socialSecurityNumber;  }
public double getGrossSales() {  return grossSales;  }
public double getCommissionRate() {  return commissionRate;  }
```

CommissionEmployee

Calculation and string transformation methods

```
public double earnings() {
    return commissionRate * grossSales;
}

@Override
public String toString() {
    return String.format("%s: %s %s\n%s: %s\n%s: %.2f\n%s: %.2f",
        "commission employee", firstName, lastName,
        "social security number", socialSecurityNumber,
        "gross sales", grossSales,
        "commission rate", commissionRate);
}
```

Method Overriding (方法重写)

- If a subclass has the same method (signature) as declared in the super class, it is known as method overriding in Java.
- Method overriding is used to provide the specific implementation of a method which is already provided by its superclass.
- Overriding is for instance methods
  - Static methods CANNOT be overridden, but can be hidden (see next lecture)
  - Class fields CANNOT be overridden, but can be hidden (see later)

Overriding `toString()` Method

- `toString()` is one of the methods that every class inherits directly or indirectly from class `Object`.
  - Returns a `String` that "textually represents" an object.
  - Called implicitly whenever an object must be converted to a `String` representation (e.g., `System.out.println(objRef)`)
- Class `Object`'s `toString()` method returns a `String` that includes the name of the object's class.
  - If not overridden, returns something like `"CommissionEmployee@70dea4e"` (the part after @ is the hexadecimal representation of the hash code of the object)
  - This is primarily a placeholder that can be overridden by a subclass to specify customized `String` representation.

Overriding `toString()` Method

- To override a superclass's method, a subclass must declare a method with the same signature as the superclass method.
- @Override annotation (注解)
  - Optional, but helps the compiler to ensure that the method has the same signature as the one in the superclass

```
@Override
public String toString() { … }
```

What happens if we change toString to tostring, with/without @Override?

Method Overriding

```
class Grandpa {
    public void hi()
    {
        System.out.println("I'm grandpa");
    }
}

class Dad extends Grandpa {
    public void hi()
    {
        System.out.println("I'm dad");
    }
}

class Me extends Dad {

    public void hi(String name)
    {
        System.out.println("I'm " + name);
    }
}
```

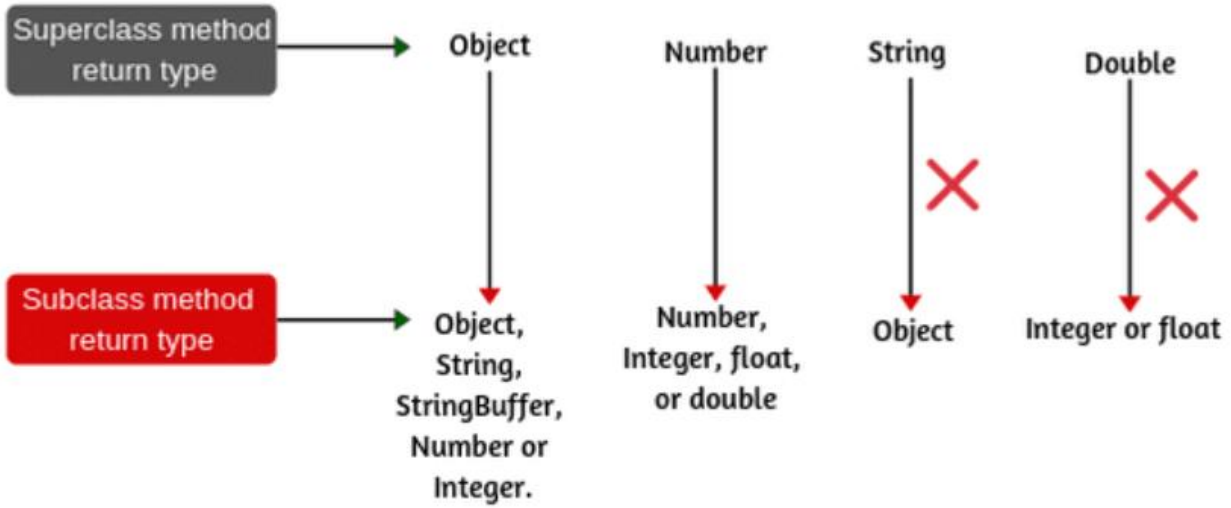
```
public class OverrideDemo {
    public static void main(String[] args) {
        Grandpa g = new Grandpa();
        Dad d = new Dad();
        Me m = new Me();

        g.hi();
        d.hi();
        m.hi();
        m.hi( name: "Joe");
    }
}
```

What's the output?

Method Overriding

- When overriding a method in a subclass, the signature must match, the return type should:
  - Either be the same
  - Or be a subtype of the return type of the superclass's method (an overridden method can have a more specific return type)



BasePlusCommissionEmployee

```
public class BasePlusCommissionEmployee extends CommissionEmployee {
    private double baseSalary;

    public BasePlusCommissionEmployee(String first, String last, String ssn,
                                      double sales, double rate, double salary) {
        super(first, last, ssn, sales, rate);
        setBaseSalary(salary);
    }

    public void setBaseSalary(double salary) {
        baseSalary = (salary < 0.0) ? 0.0 : salary;
    }
    ...
```

Added a new field

Its own constructor. In Java, constructors are not class members and are not inherited by subclasses

The super keyword

- The super keyword can be used to invoke a superclass's constructor
- Invocation of a superclass constructor must be the first line in the subclass constructor. This ensures that properties inherited from the superclass are set up first correctly
- If super is not explicitly invoked, the compiler automatically inserts a call to the no-argument constructor of the superclass. If the super class does not have a no-argument constructor, you will get a compile-time error.

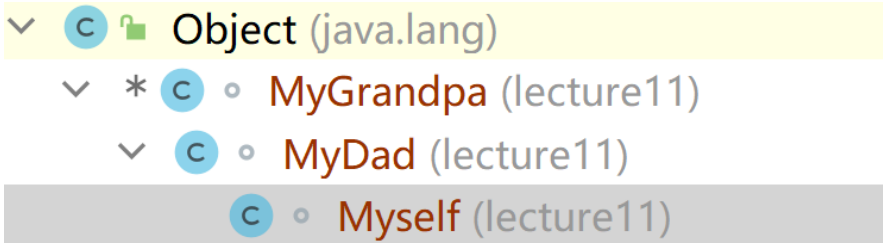
Constructor Chaining

```
class MyGrandpa {
    1 usage
    MyGrandpa(){
        System.out.println("Grandpa");
    }
}

1 usage    1 inheritor
class MyDad extends MyGrandpa {
    1 usage
    MyDad(String name){
        System.out.println("Dad " + name);
    }
}

2 usages
class Myself extends MyDad {
    1 usage
    Myself(){
        super( name: "Joe"); // comment this?
        System.out.println("Me");
    }
}
```

```
public static void main(String[] args) {
    Myself me = new Myself();
}
```




```
Grandpa
Dad Joe
Me
```

BasePlusCommissionEmployee

Overriding the two inherited methods for customized behaviors

```
public double earnings() {
    return baseSalary + ( commissionRate * grossSales );
}

@Override
public String toString() {
    return String.format("%s: %s %s\n%s: %s\n%s: %.2f\n%s: %.2f\n%s: %.2f",
        "base-salaried", firstName, lastName,
        "social security number", socialSecurityNumber,
        "gross sales", grossSales,
        "commission rate", commissionRate,
        "base salary", baseSalary);
}
```

Accessing fields of superclass

- What would happen if we compile the previous code?

Compilation error

```
BasePlusCommissionEmployee.java:35: commissionRate has private access in
CommissionEmployee
      return baseSalary + ( commissionRate * grossSales );
                            ^
BasePlusCommissionEmployee.java:35: grossSales has private access in
CommissionEmployee
      return baseSalary + ( commissionRate * grossSales );
                                             ^
...
```

```
public double earnings() {
    return baseSalary + ( commissionRate * grossSales );
}
```

Access Level Modifiers (ALL)

Modifier	Class	Package	Subclass	World
public	Y	Y	Y	Y
protected	Y	Y	Y	N
no modifier	Y	Y	N*	N
private	Y	N	N	N

- A superclass's `protected` members can be accessed by
  - members of that superclass
  - members of its subclasses
  - members of other classes in the same package

All `public` and `protected` superclass members retain their original access modifier when they become members of the subclass.

Access Level Modifiers (ALL)

Modifier	Class	Package	Subclass	World
public	Y	Y	Y	Y
protected	Y	Y	Y	N
no modifier	Y	Y	N*	N
private	Y	N	N	N

Package-private class members are inherited if the subclass is in the same package as the superclass

Accessing fields of superclass

- A subclass inherits all **public** and **protected** members of its parent, no matter what package the subclass is in.
  - These members are directly accessible in the subclass
- If the subclass is in the same package as its parent, it also inherits the parent's ***package-private*** members (those without access level modifiers)
  - These members are directly accessible in the subclass
- A subclass does not inherit the **private** members. Private fields need to be accessed using the methods (`public`, `protected`, or package-private ones) inherited from superclass.

Access Level of Overridden Method

- The access level of an overriding method can be higher, but not lower than that of the overridden method (package-private < protected < public)
- The access modifier for an overriding method can allow more, but not less, access than the overridden method (e.g., a protected instance method in the superclass can be made public, but not private, in the subclass.)

The child class must present *at least the same* interface as the parent class. Making protected/public things less visible would violate this idea

Solving the Compilation Problem

- Solution #1: using inherited methods

```
public double earnings() {
    return baseSalary + ( commissionRate * grossSales );
}
```

```
public double earnings() {
    return baseSalary + ( getCommissionRate() * getGrossSales() );
}
```

Solving the Compilation Problem

- Solution #2: declaring superclass fields as `protected`

```
public class CommissionEmployee {
    private protected String firstName;
    private protected String lastName;
    private protected String socialSecurityNumber;
    private protected double grossSales;
    private protected double commissionRate;
    ...
```

Subclass methods can refer to `public` and `protected` members inherited from the superclass simply by using the member names.

Comparing the Solutions

- Inheriting protected instance variables (solution #2) slightly increases performance, because we directly access the variables in the subclass without incurring the overhead of set/get method calls.

```
public double earnings() {
    return baseSalary + ( commissionRate * grossSales );
}
```

VS.

```
public double earnings() {
    return baseSalary + ( getCommissionRate() * getGrossSales() );
}
```

Problems of `protected` Members

- **(Problem #1)** The subclass object can set an inherited `protected` variable's value directly without using a set method. The value could be invalid, leaving the object in an inconsistent state.

- **(Problem #2)** If `protected` variables are used in many methods in the subclass, these methods will depend on the superclass's data implementation
  - Subclasses should depend only on the superclass services (e.g., `public` methods) and not on the superclass data implementation

- **(Problem #3)** A class's `protected` members are visible to all classes in the same package, this is not always desirable.

Comparing the Solutions

- From the point of good software engineering, it's better to use private instance variables (solution #1) and leave code optimization issues to the compiler.
  - Code will be easier to maintain, modify and debug.

```
public double earnings() {
    return baseSalary + ( getCommissionRate() * getGrossSales() );
}
```

VS.

```
public double earnings() {
    return baseSalary + ( commissionRate * grossSales );
}
```

More on the super Keyword

- 3 usage scenarios
  - The `super` keyword can be used to invoke a superclass's constructor (as illustrated by our earlier example)
  - If your method overrides its superclass's method, you can invoke that method of the superclass using the keyword `super`.
  - `super` can be used to refer to instance variables of the parent class.

More on the super Keyword

```
public class BasePlusCommissionEmployee extends CommissionEmployee {
    @Override
    public String toString() {
        return String.format("%s: %s %s\n%s: %s\n%s: %.2f\n%s: %.2f\n%s: %.2f",
            "base-salaried", getFirstName(), getLastName(),
            "social security number", getSocialSecurityNumber(),
            "gross sales", getGrossSales(),
            "commission rate", getCommissionRate(),
            "base salary", getBaseSalary());
    }
}

public class BasePlusCommissionEmployee extends CommissionEmployee {
    @Override
    public String toString() {
        return String.format("%s %s\n%s: %.2f",
                             "base-salaried", super.toString(),
                                "base salary", getBaseSalary());

    }
}
```

More on the super Keyword

- Three usage scenarios
  - The `super` keyword can be used to invoke a superclass's constructor (as illustrated by our earlier example)
  - If your method overrides its superclass's method, you can invoke that method of the superclass using the keyword `super`.
  - `super` can be used to refer to instance variables of the parent class.

More on the super Keyword

- Within a class, a field that has the same name as a field in the superclass hides the superclass's field, even if their types are different.
- Within the subclass, the field in the superclass cannot be referenced by its simple name. Instead, the field must be accessed through `super`
- We don't recommend hiding fields as it makes code difficult to read.

More on the super Keyword

```
class Animal{
    String color="white";
}
class Dog extends Animal{

    String color="black";

    void printColor(){
        //print color of Dog: black
        System.out.println(color);
        //print color of Animal: white
        System.out.println(super.color);
    }
}
```

```
Dog dog = new Dog();
dog.printColor();
```

Lookup Order

```
class Grandpa {

    String name = "Name: grandpa";
    int age = 99;
}

class Dad extends Grandpa {

    String name = "Name: dad";
    int height = 180;
}

class Me extends Dad {

    String name = "Name: me";
}
```

```
public static void main(String[] args) {

    Grandpa g = new Grandpa();
    Dad d = new Dad();
    Me m = new Me();

    System.out.println(m.name);
    System.out.println(m.height);
    System.out.println(m.age);
}
```

```
Name: me
180
99
```

Using CommissionEmployee

```
public class CommissionEmployeeTest
{
   public static void main( String[] args )
   {
      // instantiate CommissionEmployee object
      CommissionEmployee employee = new CommissionEmployee(
         "Sue", "Jones", "222-22-2222", 10000, .06 );

      // get commission employee data
      System.out.println(
         "Employee information obtained by get methods: \n" );
      System.out.printf( "%s %s\n", "First name is",
         employee.getFirstName() );
      System.out.printf( "%s %s\n", "Last name is",
         employee.getLastName() );
      System.out.printf( "%s %s\n", "Social security number is",
         employee.getSocialSecurityNumber() );
      System.out.printf( "%s %.2f\n", "Gross sales is",
         employee.getGrossSales() );
      System.out.printf( "%s %.2f\n", "Commission rate is",
         employee.getCommissionRate() );
```

```
        employee.setGrossSales( 500 ); // set gross sales
        employee.setCommissionRate( .1 ); // set commission rate

        System.out.printf( "\n%s:\n\n%s\n",
           "Updated employee information obtained by toString", employee );
    } // end main
} // end class CommissionEmployeeTest
```

```
Employee information obtained by get methods:

First name is Sue
Last name is Jones
Social security number is 222-22-2222
Gross sales is 10000.00
Commission rate is 0.06

Updated employee information obtained by toString:

commission employee: Sue Jones
social security number: 222-22-2222
gross sales: 500.00
commission rate: 0.10
```

Using BasePlusCommissionEmployee

```
public class BasePlusCommissionEmployeeTest
{
   public static void main( String[] args )
   {
      // instantiate BasePlusCommissionEmployee object
      BasePlusCommissionEmployee employee =
         new BasePlusCommissionEmployee(
         "Bob", "Lewis", "333-33-3333", 5000, .04, 300 );

      // get base-salaried commission employee data
      System.out.println(
         "Employee information obtained by get methods: \n" );
      System.out.printf( "%s %s\n", "First name is",
         employee.getFirstName() );
      System.out.printf( "%s %s\n", "Last name is",
         employee.getLastName() );
      System.out.printf( "%s %s\n", "Social security number is",
         employee.getSocialSecurityNumber() );
      System.out.printf( "%s %.2f\n", "Gross sales is",
         employee.getGrossSales() );
```

```
            System.out.printf( "%s %.2f\n", "Commission rate is",
               employee.getCommissionRate() );
            System.out.printf( "%s %.2f\n", "Base salary is",
               employee.getBaseSalary() );

            employee.setBaseSalary( 1000 ); // set base salary

            System.out.printf( "\n%s:\n\n%s\n",
               "Updated employee information obtained by toString",
                employee.toString() );
         } // end main
      } // end class BasePlusCommissionEmployeeTest
```

```
Employee information obtained by get methods:

First name is Bob
Last name is Lewis
Social security number is 333-33-3333
Gross sales is 5000.00
Commission rate is 0.04
Base salary is 300.00

Updated employee information obtained by toString:

base-salaried commission employee: Bob Lewis
social security number: 333-33-3333
gross sales: 5000.00
commission rate: 0.04
base salary: 1000.00
```

Inheritance in a Nutshell

- **The idea of inheritance is simple but powerful:** When you want to create a new class and there is already a class that includes some code you want, you can derive the new class from the existing one.

- The new class inherits its superclass's members—though the private superclass members are hidden (i.e., cannot be accessed) in the subclass.

Inheritance in a Nutshell

- You can customize the new class to meet your needs by including additional members and by overriding superclass members.
  - This does not require the subclass programmer to change (or even have access to) the superclass's source code.
  - Java simply requires access to the superclass's `.class` file.

- By doing this, you can reuse the fields and methods of the existing class without having to write (and debug!) them yourself.

More Examples and Observations

Superclass	Subclasses
Student	GraduateStudent, UndergraduateStudent
Shape	Circle, Triangle, Rectangle, Sphere, Cube
Loan	CarLoan, HomeImprovementLoan, MortgageLoan
Employee	Faculty, Staff
BankAccount	CheckingAccount, SavingsAccount

- Superclasses tend to be "more general" and subclasses "more specific"
- Because every subclass object *is an* object of its superclass, and one superclass can have many subclasses, the set of objects represented by a superclass is typically larger than the set of objects represented by any of its subclasses.