

# Building Java Programs

Chapter 9

Lecture 19: Inheritance, Polymorphism;

**reading: 9.2**



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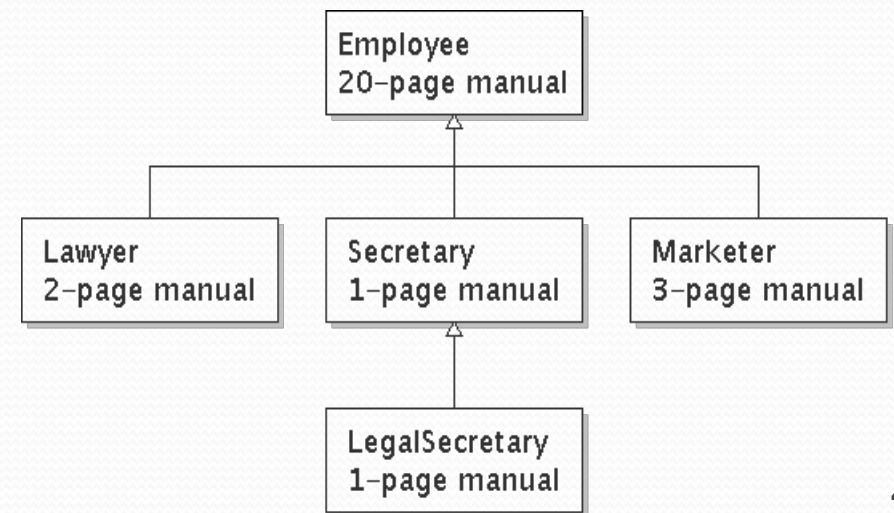
# The software crisis

- **software engineering:** The practice of developing, designing, documenting, testing large computer programs.
- Large-scale projects face many issues
  - programmers working together
  - getting code finished on time
  - avoiding redundant code
  - finding and fixing bugs
  - maintaining, reusing existing code
- **code reuse:** The practice of writing program code once and using it in many contexts.



# Law firm employee analogy

- common rules: hours, vacation, benefits, regulations ...
  - all employees attend a common orientation to learn general company rules
  - each employee receives a 20-page manual of common rules
- each subdivision also has specific rules:
  - employee receives a smaller (1-3 page) manual of these rules
  - smaller manual adds some new rules and also changes some rules from the large manual

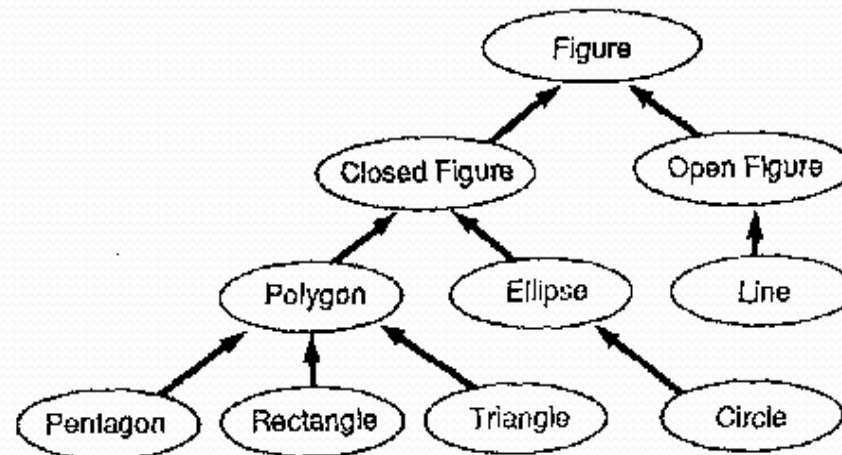


# Separating behavior

- Why not just have a 22 page Lawyer manual, a 21-page Secretary manual, a 23-page Marketer manual, etc.?
- Some advantages of the separate manuals:
  - maintenance: Only one update if a common rule changes.
  - locality: Quick discovery of all rules specific to lawyers.
- Some key ideas from this example:
  - General rules are useful (the 20-page manual).
  - Specific rules that may override general ones are also useful.

# Is-a relationships, hierarchies

- **is-a relationship:** A hierarchical connection where one category can be treated as a specialized version of another.
  - every marketer *is an* employee
  - every legal secretary *is a* secretary
- **inheritance hierarchy:** A set of classes connected by is-a relationships that can share common code.



# Employee regulations

- Consider the following employee regulations:
  - Employees work 40 hours / week.
  - Employees make \$40,000 per year, except legal secretaries who make \$5,000 extra per year (\$45,000 total), and marketers who make \$10,000 extra per year (\$50,000 total).
  - Employees have 2 weeks of paid vacation leave per year, except lawyers who get an extra week (a total of 3).
  - Employees should use a yellow form to apply for leave, except for lawyers who use a pink form.
- Each type of employee has some unique behavior:
  - Lawyers know how to sue.
  - Marketers know how to advertise.
  - Secretaries know how to take dictation.
  - Legal secretaries know how to prepare legal documents.

# An Employee class

```
// A class to represent employees in general (20-page manual).
public class Employee {
    public int getHours() {
        return 40;           // works 40 hours / week
    }

    public double getSalary() {
        return 40000.0;     // $40,000.00 / year
    }

    public int getVacationDays() {
        return 10;         // 2 weeks' paid vacation
    }

    public String getVacationForm() {
        return "yellow";   // use the yellow form
    }
}
```

- Exercise: Implement class `Secretary`, based on the previous employee regulations. (Secretaries can take dictation.)



# Redundant Secretary class

```
// A redundant class to represent secretaries.
public class Secretary {
    public int getHours() {
        return 40;           // works 40 hours / week
    }

    public double getSalary() {
        return 40000.0;      // $40,000.00 / year
    }

    public int getVacationDays() {
        return 10;          // 2 weeks' paid vacation
    }

    public String getVacationForm() {
        return "yellow";    // use the yellow form
    }

    public void takeDictation(String text) {
        System.out.println("Taking dictation of text: " + text);
    }
}
```

# Desire for code-sharing

- `takeDictation` is the only unique behavior in `Secretary`.
- We'd like to be able to say:

*// A class to represent secretaries.*

```
public class Secretary {  
    copy all the contents from the Employee class;  
  
    public void takeDictation(String text) {  
        System.out.println("Taking dictation of text: " + text);  
    }  
}
```

# Inheritance

- **inheritance:** A way to form new classes based on existing classes, taking on their attributes/behavior.
  - a way to group related classes
  - a way to share code between two or more classes
- One class can *extend* another, absorbing its data/behavior.
  - **superclass:** The parent class that is being extended.
  - **subclass:** The child class that extends the superclass and inherits its behavior.
    - Subclass gets a copy of every field and method from superclass

# Inheritance syntax

```
public class name extends superclass {
```

- Example:

```
public class Secretary extends Employee {  
    ...  
}
```

- By extending `Employee`, each `Secretary` object now:
  - receives a `getHours`, `getSalary`, `getVacationDays`, and `getVacationForm` method automatically
  - can be treated as an `Employee` by client code (seen later)

# Improved Secretary code

```
// A class to represent secretaries.  
public class Secretary extends Employee {  
    public void takeDictation(String text) {  
        System.out.println("Taking dictation of text: " + text);  
    }  
}
```

- Now we only write the parts unique to each type.
  - Secretary **inherits** `getHours`, `getSalary`, `getVacationDays`, and `getVacationForm` **methods from** `Employee`.
  - Secretary **adds the** `takeDictation` **method**.

# Implementing Lawyer

- Consider the following lawyer regulations:
  - Lawyers who get an extra week of paid vacation (a total of 3).
  - Lawyers use a pink form when applying for vacation leave.
  - Lawyers have some unique behavior: they know how to sue.
- Problem: We want lawyers to inherit *most* behavior from employee, but we want to replace parts with new behavior.

# Overriding methods

- **override:** To write a new version of a method in a subclass that replaces the superclass's version.
  - No special syntax required to override a superclass method. Just write a new version of it in the subclass.

```
public class Lawyer extends Employee {  
    // overrides getVacationForm method in Employee class  
    public String getVacationForm() {  
        return "pink";  
    }  
    ...  
}
```

- Exercise: Complete the `Lawyer` class.
  - (3 weeks vacation, pink vacation form, can sue)

# Lawyer class

```
// A class to represent lawyers.
public class Lawyer extends Employee {
    // overrides getVacationForm from Employee class
    public String getVacationForm() {
        return "pink";
    }

    // overrides getVacationDays from Employee class
    public int getVacationDays() {
        return 15;           // 3 weeks vacation
    }

    public void sue() {
        System.out.println("I'll see you in court!");
    }
}
```

- Exercise: Complete the `Marketer` class. Marketers make \$10,000 extra (\$50,000 total) and know how to advertise.



# Marketer class

```
// A class to represent marketers.
public class Marketer extends Employee {
    public void advertise() {
        System.out.println("Act now while supplies last!");
    }

    public double getSalary() {
        return 50000.0;        // $50,000.00 / year
    }
}
```

# Levels of inheritance

- Multiple levels of inheritance in a hierarchy are allowed.
  - Example: A legal secretary is the same as a regular secretary but makes more money (\$45,000) and can file legal briefs.

```
public class LegalSecretary extends Secretary {  
    ...  
}
```

- Exercise: Complete the `LegalSecretary` class.

# LegalSecretary class

```
// A class to represent legal secretaries.
public class LegalSecretary extends Secretary {
    public void fileLegalBriefs() {
        System.out.println("I could file all day!");
    }

    public double getSalary() {
        return 45000.0;          // $45,000.00 / year
    }
}
```

# Interacting with the Superclass (`super`)

**reading: 9.2**

# Changes to common behavior

- Imagine a company-wide change affecting all employees.

Example: Everyone is given a \$10,000 raise due to inflation.

- The base employee salary is now \$50,000.
  - Legal secretaries now make \$55,000.
  - Marketers now make \$60,000.
- We must modify our code to reflect this policy change.

# Modifying the superclass

```
// A class to represent employees in general (20-page manual).
public class Employee {
    public int getHours() {
        return 40;           // works 40 hours / week
    }

    public double getSalary() {
        return 50000.0;     // $50,000.00 / year
    }

    ...
}
```

- Are we finished?
- The `Employee` subclasses are still incorrect.
  - They have overridden `getSalary` to return other values.

# An unsatisfactory solution

```
public class LegalSecretary extends Secretary {  
    public double getSalary() {  
        return 55000.0;  
    }  
    ...  
}  
  
public class Marketer extends Employee {  
    public double getSalary() {  
        return 60000.0;  
    }  
    ...  
}
```

- Problem: The subclasses' salaries are based on the Employee salary, but the `getSalary` code does not reflect this.

# Calling overridden methods

- Subclasses can call overridden methods with `super`

`super.method(parameters)`

- Example:

```
public class LegalSecretary extends Secretary {
    public double getSalary() {
        double baseSalary = super.getSalary();
        return baseSalary + 5000.0;
    }
    ...
}
```



# Inheritance and constructors

- Imagine that we want to give employees more vacation days the longer they've been with the company.
  - For each year worked, we'll award 2 additional vacation days.
  - When an Employee object is constructed, we'll pass in the number of years the person has been with the company.
  - This will require us to modify our `Employee` class and add some new state and behavior.
- Exercise: Make necessary modifications to the `Employee` class.

# Modified Employee class

```
public class Employee {  
    private int years;  
  
    public Employee(int initialYears) {  
        years = initialYears;  
    }  
  
    public int getHours() {  
        return 40;  
    }  
  
    public double getSalary() {  
        return 50000.0;  
    }  
  
    public int getVacationDays() {  
        return 10 + 2 * years;  
    }  
  
    public String getVacationForm() {  
        return "yellow";  
    }  
  
}
```

# Problem with constructors

- Now that we've added the constructor to the `Employee` class, our subclasses do not compile. The error:

```
Lawyer.java:2: cannot find symbol
symbol   : constructor Employee()
location: class Employee
public class Lawyer extends Employee {
        ^
```

- The short explanation: Once we write a constructor (that requires parameters) in the superclass, we must now write constructors for our employee subclasses as well.
- The long explanation: (next slide)

# The detailed explanation

- Constructors are not inherited.
  - Subclasses don't inherit the `Employee(int)` constructor.
  - Subclasses receive a default constructor that contains:

```
public Lawyer() {  
    super();           // calls Employee() constructor  
}
```

- But our `Employee(int)` replaces the default `Employee()`.
  - The subclasses' default constructors are now trying to call a non-existent default `Employee` constructor.

# Calling superclass constructor

```
super (parameters) ;
```

- Example:

```
public class Lawyer extends Employee {  
    public Lawyer(int years) {  
        super(years); // calls Employee constructor  
    }  
    ...  
}
```

- The `super` call must be the first statement in the constructor.
- Exercise: Make a similar modification to the `Marketer` class.

# Modified Marketer class

```
// A class to represent marketers.
public class Marketer extends Employee {
    public Marketer(int years) {
        super(years);
    }

    public void advertise() {
        System.out.println("Act now while supplies last!");
    }

    public double getSalary() {
        return super.getSalary() + 10000.0;
    }
}
```

- Exercise: Modify the `Secretary` subclass.
  - Secretaries' years of employment are not tracked.
  - They do not earn extra vacation for years worked.

# Modified Secretary class

```
// A class to represent secretaries.
```

```
public class Secretary extends Employee {  
    public Secretary() {  
        super(0);  
    }  
  
    public void takeDictation(String text) {  
        System.out.println("Taking dictation of text: " + text);  
    }  
}
```

- Since `Secretary` doesn't require any parameters to its constructor, `LegalSecretary` compiles without a constructor.
  - Its default constructor calls the `Secretary()` constructor.

# Inheritance and fields

- Try to give lawyers \$5000 for each year at the company:

```
public class Lawyer extends Employee {  
    ...  
    public double getSalary() {  
        return super.getSalary() + 5000 * years;  
    }  
    ...  
}
```

- Does not work; the error is the following:

```
Lawyer.java:7: years has private access in Employee  
    return super.getSalary() + 5000 * years;  
                                   ^
```

- Private fields cannot be directly accessed from subclasses.
  - One reason: So that subclassing can't break encapsulation.
  - How can we get around this limitation?



# Improved Employee code

Add an accessor for any field needed by the subclass.

```
public class Employee {
    private int years;

    public Employee(int initialYears) {
        years = initialYears;
    }

    public int getYears() {
        return years;
    }
    ...
}

public class Lawyer extends Employee {
    public Lawyer(int years) {
        super(years);
    }

    public double getSalary() {
        return super.getSalary() + 5000 * getYears ();
    }
    ...
}
```

# Revisiting Secretary

- The `Secretary` class currently has a poor solution.
  - We set all Secretaries to 0 years because they do not get a vacation bonus for their service.
  - If we call `getYears` on a `Secretary` object, we'll always get 0.
  - This isn't a good solution; what if we wanted to give some other reward to *all* employees based on years of service?
- Redesign our `Employee` class to allow for a better solution.

# Improved Employee code

- Let's separate the standard 10 vacation days from those that are awarded based on seniority.

```
public class Employee {
    private int years;

    public Employee(int initialYears) {
        years = initialYears;
    }

    public int getVacationDays() {
        return 10 + getSeniorityBonus();
    }

    // vacation days given for each year in the company
    public int getSeniorityBonus() {
        return 2 * years;
    }
    ...
}
```

- How does this help us improve the Secretary?

# Improved Secretary code

- Secretary can selectively override `getSeniorityBonus`; when `getVacationDays` runs, it will use the new version.
  - Choosing a method at runtime is called *dynamic binding*.

```
public class Secretary extends Employee {
    public Secretary(int years) {
        super(years);
    }

    // Secretaries don't get a bonus for their years of service.
    public int getSeniorityBonus() {
        return 0;
    }

    public void takeDictation(String text) {
        System.out.println("Taking dictation of text: " + text);
    }
}
```

# Polymorphism

- **polymorphism:** Ability for the same code to be used with different types of objects and behave differently with each.
  - `System.out.println` can print any type of object.
    - Each one displays in its own way on the console.
  - `CritterMain` can interact with any type of critter.
    - Each one moves, fights, etc. in its own way.

# Coding with polymorphism

- A variable of type  $T$  can hold an object of any subclass of  $T$ .

```
Employee ed = new Lawyer();
```

- You can call any methods from the `Employee` class on `ed`.
- When a method is called on `ed`, it behaves as a `Lawyer`.

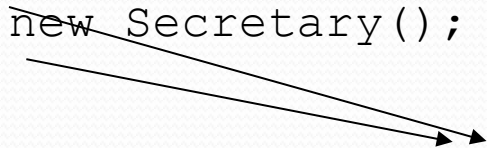
```
System.out.println(ed.getSalary());           // 50000.0  
System.out.println(ed.getVacationForm());    // pink
```

# Polymorphism and parameters

- You can pass any subtype of a parameter's type.

```
public class EmployeeMain {
    public static void main(String[] args) {
        Lawyer lisa = new Lawyer();
        Secretary steve = new Secretary();
        printInfo(lisa);
        printInfo(steve);
    }

    public static void printInfo(Employee empl) {
        System.out.println("salary: " + empl.getSalary());
        System.out.println("v.days: " + empl.getVacationDays());
        System.out.println("v.form: " + empl.getVacationForm());
        System.out.println();
    }
}
```



## OUTPUT:

```
salary: 50000.0
v.days: 15
v.form: pink
```

```
salary: 50000.0
v.days: 10
v.form: yellow
```

# Polymorphism and arrays

- Arrays of superclass types can store any subtype as elements.

```
public class EmployeeMain2 {
    public static void main(String[] args) {
        Employee[] e = { new Lawyer(), new Secretary(),
                       new Marketer(), new LegalSecretary() };

        for (int i = 0; i < e.length; i++) {
            System.out.println("salary: " + e[i].getSalary());
            System.out.println("v.days: " + e[i].getVacationDays
                ());
            System.out.println();
        }
    }
}
```

## Output:

```
salary: 50000.0
v.days: 15

salary: 50000.0
v.days: 10

salary: 60000.0
v.days: 10

salary: 55000.0
v.days: 10
```



# A polymorphism problem

- Suppose that the following four classes have been declared:

```
public class Foo {
    public void method1() {
        System.out.println("foo 1");
    }

    public void method2() {
        System.out.println("foo 2");
    }

    public String toString() {
        return "foo";
    }
}

public class Bar extends Foo {
    public void method2() {
        System.out.println("bar 2");
    }
}
```

# A polymorphism problem

```
public class Baz extends Foo {
    public void method1() {
        System.out.println("baz 1");
    }
    public String toString() {
        return "baz";
    }
}

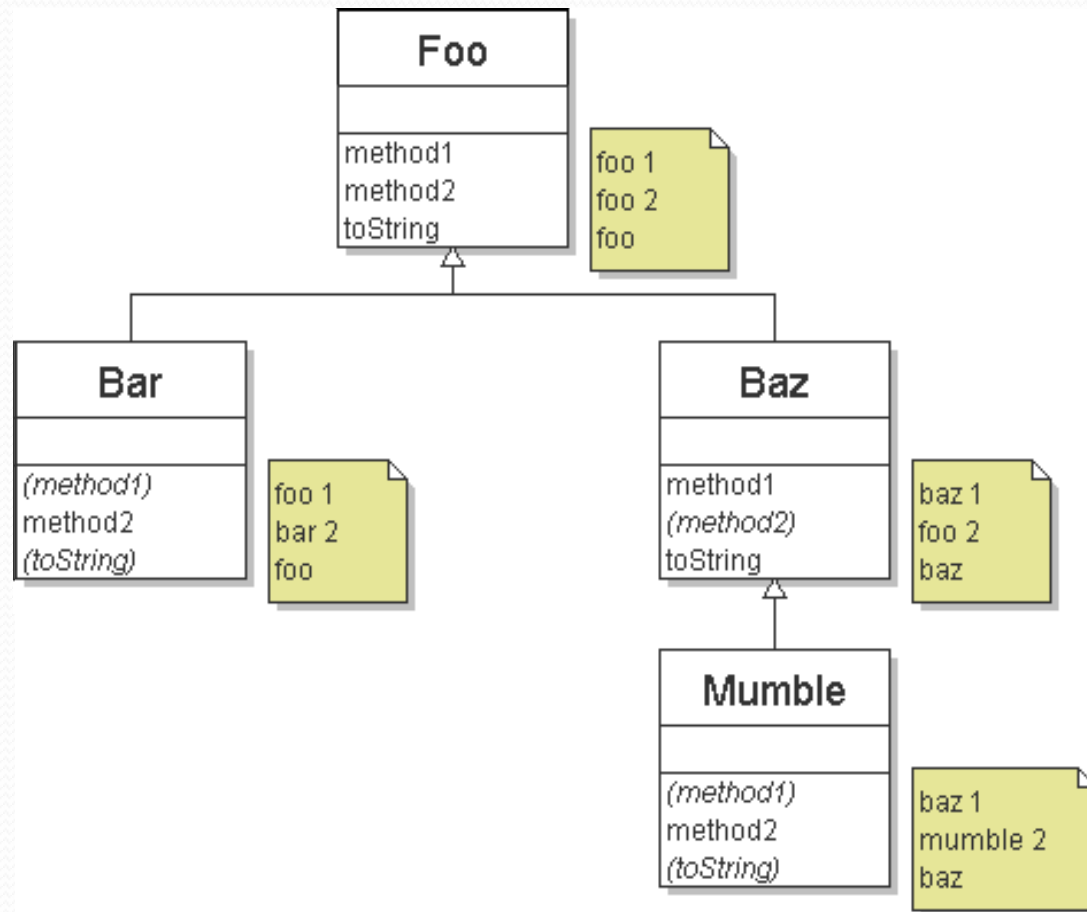
public class Mumble extends Baz {
    public void method2() {
        System.out.println("mumble 2");
    }
}
```

- What would be the output of the following client code?

```
Foo[] pity = {new Baz(), new Bar(), new Mumble(), new Foo()};
for (int i = 0; i < pity.length; i++) {
    System.out.println(pity[i]);
    pity[i].method1();
    pity[i].method2();
    System.out.println();
}
```

# Diagramming the classes

- Add classes from top (superclass) to bottom (subclass).
- Include all inherited methods.



# Finding output with tables

<b>method</b>	<b>Foo</b>	<b>Bar</b>	<b>Baz</b>	<b>Mumble</b>
method1	foo 1	<i>foo 1</i>	baz 1	<i>baz 1</i>
method2	foo 2	bar 2	<i>foo 2</i>	mumble 2
toString	foo	<i>foo</i>	baz	<i>baz</i>

# Polymorphism answer

```
Foo[] pity = {new Baz(), new Bar(), new Mumble(), new Foo()};  
for (int i = 0; i < pity.length; i++) {  
    System.out.println(pity[i]);  
    pity[i].method1();  
    pity[i].method2();  
    System.out.println();  
}
```

- **Output:**

```
baz  
baz 1  
foo 2  
  
foo  
foo 1  
bar 2  
  
baz  
baz 1  
mumble 2  
  
foo  
foo 1  
foo 2
```

# Another problem

- The order of the classes is jumbled up.
- The methods sometimes call other methods (tricky!).

```
public class Lamb extends Ham {
    public void b() {
        System.out.print("Lamb b    ");
    }
}

public class Ham {
    public void a() {
        System.out.print("Ham a    ");
        b();
    }

    public void b() {
        System.out.print("Ham b    ");
    }

    public String toString() {
        return "Ham";
    }
}
```

# Another problem 2

```
public class Spam extends Yam {
    public void b() {
        System.out.print("Spam b    ");
    }
}

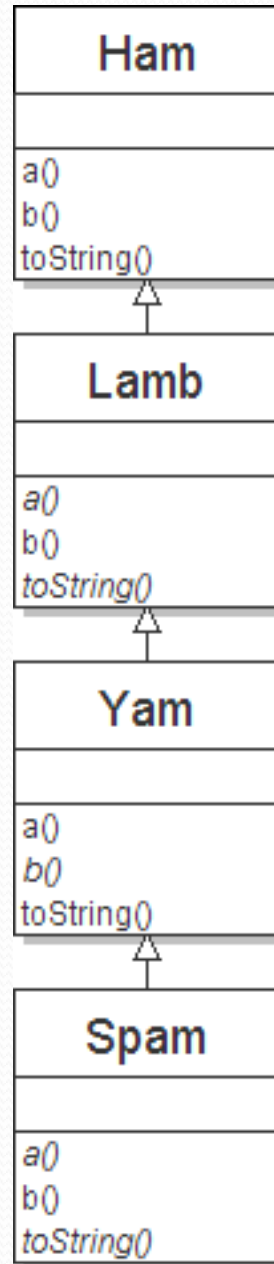
public class Yam extends Lamb {
    public void a() {
        System.out.print("Yam a    ");
        super.a();
    }

    public String toString() {
        return "Yam";
    }
}
```

- What would be the output of the following client code?

```
Ham[] food = {new Lamb(), new Ham(), new Spam(), new Yam()};
for (int i = 0; i < food.length; i++) {
    System.out.println(food[i]);
    food[i].a();
    System.out.println();           // to end the line of output
    food[i].b();
    System.out.println();           // to end the line of output
    System.out.println();
}
```

# Class diagram





# Polymorphism at work

- Lamb inherits Ham's a. a calls b. But Lamb overrides b...

```
public class Ham {
    public void a() {
        System.out.print("Ham a ");
        b();
    }
    public void b() {
        System.out.print("Ham b ");
    }
    public String toString() {
        return "Ham";
    }
}

public class Lamb extends Ham {
    public void b() {
        System.out.print("Lamb b ");
    }
}
```

- Lamb's output from a:

Ham a      **Lamb b**

# The table

<b>method</b>	<b>Ham</b>	<b>Lamb</b>	<b>Yam</b>	<b>Spam</b>
a	Ham a <b>b()</b>	<i>Ham a</i> <b>b()</b>	Yam a Ham a <b>b()</b>	<i>Yam a</i> <i>Ham a</i> <b>b()</b>
b	Ham b	Lamb b	Lamb b	Spam b
toString	Ham	<i>Ham</i>	Yam	<i>Yam</i>

# The answer

```
Ham[] food = {new Lamb(), new Ham(), new Spam(), new Yam()};  
for (int i = 0; i < food.length; i++) {  
    System.out.println(food[i]);  
    food[i].a();  
    food[i].b();  
    System.out.println();  
}
```

- **Output:**

```
Ham  
Ham a    Lamb b  
Lamb b  
  
Ham  
Ham a    Ham b  
Ham b  
  
Yam  
Yam a    Ham a    Spam b  
Spam b  
  
Yam  
Yam a    Ham a    Lamb b  
Lamb b
```

# Casting references

- A variable can only call that type's methods, not a subtype's.

```
Employee ed = new Lawyer();  
int hours = ed.getHours(); // ok; this is in Employee  
ed.sue(); // compiler error
```

- The compiler's reasoning is, variable `ed` could store any kind of employee, and not all kinds know how to `sue`.
- To use `Lawyer` methods on `ed`, we can type-cast it.

```
Lawyer theRealEd = (Lawyer) ed;  
theRealEd.sue(); // ok  
  
( (Lawyer) ed ).sue(); // shorter version
```

# More about casting

- The code crashes if you cast an object too far down the tree.

```
Employee eric = new Secretary();  
(Secretary) eric.takeDictation("hi"); // ok  
((LegalSecretary) eric).fileLegalBriefs(); // exception  
  
// (Secretary object doesn't know how to file briefs)
```

- You can cast only up and down the tree, not sideways.

```
Lawyer linda = new Lawyer();  
((Secretary) linda).takeDictation("hi"); // error
```

- Casting doesn't actually change the object's behavior.  
It just gets the code to compile/run.

```
((Employee) linda).getVacationForm() // pink (Lawyer's)
```