Building Java Programs

Chapter 9
Lecture 19: Inheritance, Polymorphism;

reading: 9.2
I started a task force to eliminate redundancies in our internal processes.

Really? I'm doing the same thing.
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.

![Inheritance Hierarchy Diagram](image)
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:

```java
// 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

```java
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)
```
// 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.

```java
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.
// 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.

```java
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 \((\text{super})\)

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

```java
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:

```java
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.
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";
    }
}

Modified Employee class
Problem with constructors

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

```java
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:

    ```java
    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

\[ \text{super(parameters);} \]

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

- The \text{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.
// 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:

```java
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.

```java
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.

```java
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*.

```java
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);
    }
}
```
CSE 142 Critters

- Ant
- Bird
- Hippo
- Vulture
- Husky (creative)

**behavior:**
- **eat**
- **fight**
- **getColor**
- **getMove**
- **toString**

- eating food
- animal fighting
- color to display
- movement
- letter to display
A Critter subclass

```java
class name extends Critter {
    ...}

class Critter {
    public boolean eat()
    public Attack fight(String opponent)
        // ROAR, POUNCE, SCRATCH
    public Color getColor()
    public Direction getMove()
        // NORTH, SOUTH, EAST, WEST, CENTER
    public String toString()
}
```
How the simulator works

- "Go" → loop:
  - move each animal (getMove)
  - if they collide, fight
  - if they find food, eat

- Simulator is in control!
  - getMove is one move at a time
    - (no loops)
  - Keep state (fields)
    - to remember future moves
Development Strategy

- Do one species at a time
  - in ABC order from easier to harder (Ant → Bird → …)
  - debug `printlns`

- Simulator helps you debug
  - smaller width/height
  - fewer animals
  - "Tick" instead of "Go"
  - "Debug" checkbox
  - drag/drop to move animals
## Critter exercise: Cougar

- Write a critter class `Cougar`:

<table>
<thead>
<tr>
<th>Method</th>
<th>Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>constructor</td>
<td><code>public Cougar()</code></td>
</tr>
<tr>
<td>eat</td>
<td>Always eats.</td>
</tr>
<tr>
<td>fight</td>
<td>Always pounces.</td>
</tr>
<tr>
<td>getColor</td>
<td>Blue if the Cougar has never fought; red if he has.</td>
</tr>
<tr>
<td>getMove</td>
<td>Walks west until he finds food; then walks east until he finds food; then goes west and repeats.</td>
</tr>
<tr>
<td>toString</td>
<td>&quot;C&quot;</td>
</tr>
</tbody>
</table>
Ideas for state

• You must not only have the right state, but update that state properly when relevant actions occur.

• Counting is helpful:
  • How many total moves has this animal made?
  • How many times has it eaten? Fought?

• Remembering recent actions in fields is helpful:
  • Which direction did the animal move last?
    • How many times has it moved that way?
  • Did the animal eat the last time it was asked?
  • How many steps has the animal taken since last eating?
  • How many fights has the animal been in since last eating?
import java.awt.*; // for Color

public class Cougar extends Critter {
    private boolean west;
    private boolean fought;

    public Cougar() {
        west = true;
        fought = false;
    }

    public boolean eat() {
        west = !west;
        return true;
    }

    public Attack fight(String opponent) {
        fought = true;
        return Attack.POUNCE;
    }

    ...
}
...  

public Color getColor() {
    if (fought) {
        return Color.RED;
    } else {
        return Color.BLUE;
    }
}

public Direction getMove() {
    if (west) {
        return Direction.WEST;
    } else {
        return Direction.EAST;
    }
}

public String toString() {
    return "C";
}
# Critter exercise: Snake

<table>
<thead>
<tr>
<th>Method</th>
<th>Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>constructor</td>
<td><code>public Snake()</code></td>
</tr>
<tr>
<td>eat</td>
<td>Never eats</td>
</tr>
<tr>
<td>fight</td>
<td>always forfeits</td>
</tr>
<tr>
<td>getColor</td>
<td>black</td>
</tr>
<tr>
<td>getMove</td>
<td>1 E, 1 S; 2 W, 1 S; 3 E, 1 S; 4 W, 1 S; 5 E, ...</td>
</tr>
<tr>
<td>toString</td>
<td>&quot;S&quot;</td>
</tr>
</tbody>
</table>
Determining necessary fields

- Information required to decide what move to make?
  - Direction to go in
  - Length of current cycle
  - Number of moves made in current cycle

- Remembering things you've done in the past:
  - an int counter?
  - a boolean flag?
import java.awt.*;   // for Color

public class Snake extends Critter {
    private int length;  // # steps in current horizontal cycle
    private int step;    // # of cycle's steps already taken

    public Snake() {
        length = 1;
        step = 0;
    }

    public Direction getMove() {
        step++;
        if (step > length) {  // cycle was just completed
            length++;
            step = 0;
            return Direction.SOUTH;
        } else if (length % 2 == 1) {
            return Direction.EAST;
        } else {
            return Direction.WEST;
        }
    }

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