Focus: The Connection between OO Designs and OO Code

- Review object-oriented concepts.
- Introduce the UML design notation.
- Show the relationship between designs and program code.
- Demonstrate the process of implementing a design.

Object-Oriented Paradigm

- “Programming as simulation.”
  Objects represent “real world” or virtual entities.
- Entities have state and behavior.
  - State is hidden.
  - Behavior is accessed through public interfaces.

Interacting With an Object

- State viewed through interfaces:
  - Gauges.
  - Tachometer.
- Actions through access methods.
  - Gas pedal.
  - Steering wheel.

Objects & Encapsulation

- Public methods supply services.
- Private representation of object state.
- Private method implementations.
- Language enforcement of encapsulation.

Abstraction Mechanisms in Programming Languages

- Control abstraction:
  Loops, if-then-else constructs.
- Procedural abstraction:
  Procedures, functions, algorithms.
- Data abstractions:
  Abstract data type (ADT).
- Object abstraction: Class

Names identify realizations of abstractions.
Names in Software Engineering

- Juliet Capulet: "What’s in a name? That which we call a rose By any other name would smell as sweet."
- Was Juliet right?
- Why do we talk about names in a software engineering course?
- Names should be descriptive of their use.

How not to name things
(from "How to write unmaintainable code")

- Take names from a baby naming book: Fred, Susan, Bob, Jane are great names.
- Single letter names.
- Creative misspelling.
- Be abstract: it, data, stuff.
- Use acronyms.
- Use alternate vocabulary to refer to the same action: display, show, present.
- Use names from other languages.

Stack ADT

- Private state: Stores values of stack items.
- Public operations: push, pop, top, isEmpty, isFull.
Stack object --- instantiated stack ADT.

General Properties of Stack Objects (& other objects)

- May have several instantiated stack objects.
- Each stack object has its own representation. Each object may have different items stored.
- All stack items respond to the same messages. Operations encoded as methods in the class definition.

To Develop an OO System

- Identify object services.
- Identify system objects.
- Determine connection between objects.
- Implement by defining object classes.

Modeling Classes & Objects

- Class: description of a set of similar objects.
- Class definition:
  - Class name.
  - State representation.
  - Public interface.
  - Private implementation of methods.
Unified Modeling Language (UML)

- Unifies several prior modeling notations: Booch, Rumbaugh (OMT), Jacobson, Shenker-Mellor, Coad-Youurd, Wirfs-Brock.
- UML diagram types:
  - Class diagrams, object diagrams, use case diagrams, interaction diagrams, package diagrams, sequence diagrams, state diagrams, activity diagrams, deployment diagrams, component diagrams.
- Owned and managed by the Object Modeling Group.

UML is a family of model types

UML Class Model

<table>
<thead>
<tr>
<th>Classname</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attribute_1</td>
</tr>
<tr>
<td>...</td>
</tr>
<tr>
<td>Service_1</td>
</tr>
<tr>
<td>...</td>
</tr>
</tbody>
</table>

Class Stack and Two Stack Objects in UML

```
Class IntStack
  - StackRep: ArrayList<integers>
    + top: int
    + size: int

  + push(): void
    + pop(): int
    + isEmpty(): boolean
    + isFull(): boolean

// Example
s1.IntStack = ...
```

Methods (Member Functions)

- Provide an object’s services.
  - Stack services: push, pop, top, isEmpty, and isFull.
- Public interface: method names & parameters.
- Private method bodies: implement the method.

Constructors

- Methods that define how an object is initialized.
- Run when an object is first created.
- Can be parameterized.
- One class can have several constructors.
  - Pattern selects a constructor.
Objects Are Dynamically Created at Run Time

• To create stack objects in Java:
  Stack s1 = new Stack();
  Stack s2 = new Stack();
• Stacks s1 and s2 reference different stacks.

Push Items Onto the Stacks

\[
\begin{array}{c|c|c}
\text{s1} & \text{s2} \\
\hline
5 & 7 \\
7 & 30 \\
5 & 20 \\
10 & 30 \\
\end{array}
\]

Queue Example

• Attributes:
  - Queue representation, length, max size, location of front & back of Queue.
• Operations or functions:
  - Queue(), ~Queue() (in c++)
  - Enqueue(DataItem data), Dequeue()
  - Empty(), Full()

UML Class Diagram of the Queue Class

• Private attributes & operations indicated with a -
• Public attributes & operations indicated with a +

Information Hiding

• Module implementation details are inaccessible (hidden) from other modules.
  Ex: front, back, & length of prior example.
• Why limit access?
  - Protects module against outside interference.
  - Prevents other modules from depending on implementation details.
  - Modification is easier: Local effects of changes.

Encapsulation

• Think of an ADT as a unit or object: don’t worry about implementation details (from a higher level of abstraction).
• Again: The combination of data (characteristics) with the methods (behavior) for manipulating an object.
  Ex: Queue class.
Queue Java Implementation

class QueueNode {
    DataItem item;
    QueueNode link;
}

class Queue {
    private QueueNode front;
    private QueueNode back;
    private int length;
    // default no-arg constructor
    public boolean Empty() {
        return (length == 0);
    }
}

Java Queue (2)

public void Enqueue (DataItem itemvalue) {
    QueueNode temp = new QueueNode();
    temp.item = itemvalue;
    temp.link = null;
    if (back == null) {
        front = back = temp;
    } else {
        back.link = temp;
        back = temp;
    }
    length ++;
}

A Class

- The template for an object.
- The primary ADT.
- Follows OOD nomenclature.
- Provides encapsulation.
- Supports information hiding: Separates interface and implementation.

Other OO Terms

- Destructors: methods that free the dynamic storage used to store an object’s state.
  Not needed in Java; required in C++
- Message passing: mechanism used to communicate with objects.
  Call to an objects method, with parameters.

Class Links

- Represent connections between objects.
- Link types represent relationships:
  - Non-hierarchical associations.
  - Part-of associations: aggregation & composition.
  - Is-a relationship: inheritance.
  - Use dependencies: transient connections.

Non-hierarchical Associations in a Class Diagram

Mother   has a 1  Child

Associations:
- Can have multiplicity indicators.
- Can have direction.
Association Implementation

```java
class Child {
    ...
    private Mother mom;
    ...
}
```

- Variable `mom` references mother object.
- Relationship created by setting `mom` variable.

Does the implementation match the class diagram?

```java
class Mother {
    ...
    private Child[] theKids = new Child[20];
    ...
}
```

Creating the Relationships

```java
Mother theMom = new Mother();
Child sue = new Child();
Child tom = new Child();
theMom.addChild(tom);
theMom.addChild(sue);
tom.setMom(theMom);
sue.setMom(theMom);
```

Keep Instance Variables Private

- You can modify the representation without changing client code.
  - You might change the array representation of `theKids` to an implementation of the Java Collection interface.
  - Keeping `theKids` private allows this change without affecting an unknown number of clients.

Composition

- One software entity is built out of other entities.
- Composition: a stronger form of aggregation.
- Precise definitions of aggregation continue to be debated, but composition is clear.
Implementing Composition

- Component object instantiated by containing class
  ```java
  class Table {
    private Legs[] legs = new Legs[4];
    private Top theTop = new Top();
    ...
  }
  ```

Composition: Objects Composed of Other Objects

- Range sensors have a radial or array pattern; they are placed in a location on a robot; users can print or change sensor values.
- Range sensors consist of 4 ultrasonic sensors.
- Each ultrasonic sensor has a value. Users can get or set values.

Composition Example: Ultrasonic Class

```java
class Ultrasonic {
  private double value;
  // instance variable
  public Ultrasonic(float v) {
    value = v;
  }
  public double getValue() {
    return value;
  }
  public void setValue(double v) {
    value = v;
  }
}
```

Ultrasonic has no reference to its containing RangeSensor object.

Containing Class: RangeSensor

```java
public class RangeSensor {
  private Ultrasonic ultras[4] = new Ultrasonic[4];
  private double height;
  private double offset;
  public RangeSensor(double iVal, double h, double o) {
    for (i=0; i < MAX; i++) ultras[i].set_value(iVal);
    height=h; offset=o;
  }
  void printValues() {…}
  void changeUltraValue(int ultraNum, double val) {…}
}
```

Polymorphism

- "Ability to hide different implementations behind a common interface" (Taylor, 1990).
- "Single interface, many implementations" (Entsminger, 1995).
- "Literally, the ability to have many forms" (Graham, 1991).
**Polymorphism in OO Software**

- Supported by dynamic binding (done at run-time, not at compile-time) and overloading.
  - Objects of a declared class can be replaced at run-time with objects of any of its subclasses.
  - Dynamic Binding: the method that is invoked depends on the object that is bound at run-time to a variable rather than the declared type of the variable.
- Example:
  ```java
  public int m(RangeSensor r) {
      r.printValues();
  }
  ```
  At runtime any RangeSensor subclass object may be bound to r. A printValues method defined in the subclass is the one invoked.

**Inheritance Supports Polymorphism**

- Defines a class that is a specialization of another class.
- Generalization/Specialization in UML.

**Inheritance Implements Specialization.**

In Java, use the key word extends:
```
class Monkey extends Animal {
    ...
}
```

**Inheritance Terms**

- Inheritance: a mechanism to implement a generalization-specialization relationship.
- Subclass: the specialized, extended or derived class.
- Superclass: the more general class in the relationship. The class that is extended.

**Hierarchy Example**

```
Person
  name, id
  getName()

Student
  major
  getName()
  addClass()
  dropClass()

Faculty
  department
  getName()
  gradeStudent()
```

**Generalization Class (Base Class or Superclass)**

```
class Person {
    private String name;
    private String id;
    public Person(String n, String ident) {
        name = new String(n);
        id = new String(ident);
    }
    public String getName() { return name; }
}
```
Specialization Class
Derived Class / Subclass

class Student extends Person {
private String major;
public Student(String name, String id, String m) {
this.super(name, id); major = m;
}
public String getName() {
    return "Student name: " + this.super.getName() + "; Major: " + major;
}
public addClass(...); ...
public dropClass(...);
}

Another Specialization Class

class Faculty extends Person {
private Department dept;
public Faculty(String name, String id, String d) {
this.super(name, id); dept = d;
}
public String getName() {
    return "Faculty name: " + this.super.getName() + "; Department: " + dept;
}
public gradeStudent(...);
}

Creating & Using Specialization Class Objects in Client Code

{  Person t = new Person("Tom", "1234");  Student s = new Student("Sally", "4321", "CS");  Faculty j = new Faculty("Jim", "987", "CS");  t.getName();  s.getName();  s.addClass(...);  j.gradeStudent(...);  Person s2 = new Student("Audrey", "789", "Math");  s2.getName();  // Which getName() runs?  // s2.addClass();  // would not compile. Why?  }

Inheritance Details

• A subclass cannot directly access private members of its base class.
• Creating a subclass does not affect its base class's source code.
• To resolve polymorphism: At runtime, the class hierarchy is searched upward to find the first definition of a member function — specialization wins!

Dynamic Binding (Yo-Yo) Example

public class A {
private int x = 1;
public String doIt() {return hi() + "x = " + x;}
public String hi() {return "Hi, I'm A. ";}
}
public class B extends A {
private int x = 2;
public String doIt() {
    return hi() + "x = " + x + " " + super.doIt();
}
public String hi() {return "Hi, I'm B. ";}
}
public class C {
public String m(A a) { return a.doIt();}
public static void main(String[] args){
    A testAObj = new B();
    C c = new C();
    System.out.println( c.m(testAObj) );
}
}

What happens when it runs?

% java C
Hi, I'm B. x = 2 Hi, I'm B. x = 1

Use Inheritance Only for "is a" Relationships

• Use inheritance only when the subclass is a true specialization of the superclass.
  • There should be a generalization-specialization relationship.
  • Subclass objects should be clearly a specialization.
  • A student is a specialized person; it has all of the properties of an animal and some additional ones.
Java Interfaces

- Java interfaces define operations & type signatures

```java
interface PointI {
    public float x(); /* Show my x coordinate */
    public float y(); /* Show my y coordinate */
    public Point add(PointI p); /* Point addition */
}
```

Implementing an Interface

class Point implements PointI {
    /* representation: x, y are Cartesian coordinate values. */
    private float x, y;
    /* Construct myself as an origin point */
    public Point() {}
    /* Construct myself with given x & y coordinates */
    public Point(float xval, float yval) {
        x = xval;
        y = yval;
    }
}

Class Point Methods

```java
/* Show my coordinates */
public float x() {return x;}
public float y() {return y;}

/* Point addition */
public Point add(Point p) {
    float sumX = x + p.x();
    float sumY = this.y() + p.y();
    return new Point(sumX,sumY); }
```

Class Point Implements Interface PointI (in UML)

Interfaces Can Inherit From Other Interfaces

- Pmult extends PointI with Point multiplication:

```java
interface Pmult extends PointI {
    public Point mult(Pmult p);
    /* Point multiplication */
}
```
Use Links / Use Dependencies

- Represent a transient connection:
  - Link not represented in class state.
  - Link active during method activation only.
- Object whose services will be used is passed in as a method parameter.

Ex. Use Dependency/Link: Adoption

- Class Mother has a method adoptChild, which adds an adopted Child to the family:
- Use an AdoptionAgency method:
  ```java
  public void adoptChild(AdoptionAgency theAgency) {
      addChild(theAgency.getChild());
  }
  ```

Use Link between Mother, Child, & AdoptionAgency in UML

Class Link Summary

- Non-hierarchical association:
  - Relationship: no clear whole-part or specialization relationship.
  - Duration: part of the class state; It persists over the lifetime of the class object.
  - Implementation: define an instance variable that is a reference to the associated link.
    Use container class to support multiplicity.

Class Link Summary (2)

- Composition association:
  - Relationship: clear whole-part relationship.
  - Duration: part of the class state; It persists over the lifetime of the class object.
  - Implementation: define an instance variable that is a reference to the associated link.
    Use a container class to support multiplicity.

Class Link Summary (3)

- Inheritance link:
  - Relationship: generalization-specialization.
  - Duration: permanent part of the static definition of the subclass.
  - Implementation: use inheritance. In Java, the subclass extends the superclass.
Class Link Summary (4)

- Use links/use dependencies:
  - Relationship: one class object uses the services of another class object.
  - Duration: transient; Exists only while the client or server methods are active.
  - Implementation: client class method has a formal parameter which is a reference to the server class. The client invokes a server method.

Example Design: Cave Game

- Player visits a cave looking for treasure.
- Move from room to room.
- Purely text based: predates GUI’s.
  - Rooms described via textual description only.
  - Players must construct their own maps, on paper.

Cave Game Player Options

- As you go from room to room, you can:
  - Look at the room,
  - Go into an adjacent room or through an adjacent door,
  - Pick up an object in the room, or
  - Drop an object that you are carrying.

Cave Game Commands

After reading the textual description a player types one of the following commands:

“n, s, e, w, u, d” for north, south, east, west, up, or down.
Implementing the Design

- The design evolves during implementation.
- Methods added to class Room:
  - void exit(int direction, Player p)
  - void addItem(Item i) and removeItem(Item i)
  - Item[] getRoomContents()

Implementing the Design (2)

- Methods added to class Player:
  - boolean haveItem(Item i)
  - Void setLoc(Room r)
  - Room getLoc()
  - String showMyThings()
  - boolean handsFull()
  - boolean handsEmpty()

Class Model Version 2

Class Player Code

```java
class Player {
    private Room myLoc;
    private Item[] myThings = new Item[2];
    private int itemCount = 0;
    public void setRoom(Room r){
        myLoc = r;
    }
    public String look() {
        return myLoc.getDesc();
    }
    public void go(int direction){
        myLoc.exit(direction,this);
    }
    public void pickUp(Item i){
        if (itemCount < 2) {
            myThings[itemCount] = i;
            itemCount++;
            myLoc.removeItem(i);
        }
    }
}
```

Class Player Code (2)

```java
class Room implements CaveSite {
    private String description;
    private CaveSite[] side = new CaveSite[6];
    private Vector contents = new Vector();
    Room() {
        side[0] = new Wall();
        side[1] = new Wall();
        side[2] = new Wall();
        side[3] = new Wall();
        side[4] = new Wall();
        side[5] = new Wall();
    }
}
```

Class Room Code
Class Room Code - Navigation

```java
public void enter(Player p) {
p.setLoc(this);
}
public void exit(int direction, Player p){
    side[direction].enter(p);
}
```

Class Wall Code

```java
class Wall implements CaveSite {
    public void enter(Player p) {
        System.out.println("Ouch! That hurts.");
    }
}
```

Class Door Code

```java
class Door implements CaveSite {
    private Key myKey;
    private CaveSite outSite;
    private CaveSite inSite;
    Door(CaveSite out, CaveSite in, Key k){
        outSite = out;
        inSite = in;
        myKey = k;
    }
}
```

Door Navigation Code

```java
public void enter(Player p){
    if (p.haveItem(myKey)) {
        System.out.println("Your key works! The door creaks open …");
        if (p.getLoc() == outSite) inSite.enter(p);
        else if (p.getLoc() == inSite) outSite.enter(p);
    } else {
        System.out.println("You don’t have the key for this door!");
    }
}
```

Common Implementation Problems

- Distribution of class functionality.
- Not recognizing dynamic binding: Objects know their class & will use the right method.
- Poor encapsulation.
- Separating the user interface with the guts of the system: Model - View separation, or Model - View - Controller design pattern.
- Creating object configurations: Factory or Abstract Factory design pattern.

Summary

- Review of OO concepts.
- UML class & instance models.
- Class links: non-hierarchical, whole-part, generalization-specialization, & use links.
- Design-to-code process.
- Note: UML models vary, depending on level of abstraction.