Outline

- **Access Control**
  - Access Control
  - Class Access

- **Code Reuse**
  - Reusing Class

- **Inheritance**
  - Composition vs Inheritance
  - Composition syntax
  - Inheritance syntax
  - final

- **Polymorphism**
  - Interface & Implementation
  - Dynamic Binding
  - Abstract classes
  - Constructors
  - Pure Inheritance vs Extension
Java Access Control

- Introduction
- Function Templates
- Overloading Function Templates
- Class Templates
- Nontype Parameters and Default Types for Class Templates
Java Access Control

- **public**
  - Interface Access

- **private**
  - Only Accessible Within the class

- **protected**
  - “Sort of private”
    - deals with inheritance
“Friendly”

• Default access: no keyword

• **Public**
  – Other members of the same package

• **Private**
  – Anyone outside the package
  – Easy interaction for related classes (that you place in the same package)
  – Also referred to as “package access”
Protected

• **protected**
  – Inheritors (and the package) can access protected members
  BUT
  – They are then vulnerable to changes in the base-class implementation
  – Users of classes not in the class hierarchy are prevented from accessing protected members
package c05.dessert;

public class Cookie {
    public Cookie() {
        System.out.println("Cookie constructor");
    }
    void bite()
    { System.out.println("bite"); }
} ///:~

//: c05:Dinner.java
// Uses the library.
import c05.dessert.*;

public class Dinner {
    public Dinner() {
        System.out.println("Dinner constructor");
    }
    public static void main(String[] args) {
        Cookie x = new Cookie();
        //! x.bite(); // Can't access
    }
} ///:~
//: c05:IceCream.java
// Demonstrates "private" keyword.

class Sundae {
    private Sundae() {}
    static Sundae makeASundae() {
        return new Sundae();
    }
}

public class IceCream {
    public static void main(String[] args) {
        //! Sundae x = new Sundae();
        Sundae x = Sundae.makeASundae();
    }
} ///:~
Class Access

- Classes as a whole can be **public** or “friendly”
- Only one **public** class per file, usable outside the package
- All other classes “friendly,” only usable within the package
Reusing Classes

• When you need a class, you can:
  1) Get the perfect one off the shelf (one extreme)
  2) Write it completely from scratch (the other extreme)
  3) Reuse an existing class with composition
  4) Reuse an existing class or class framework with inheritance
Composition vs. Inheritance

Pure composition
Code reuse

Pure inheritance
Interface duplication for interchangeable objects

Inherit to extend the interface

Car
- Wheel[]
- Window[]
- Door[]
- Engine

Shape
- draw()
- erase()

Circle
- draw()
- erase()

Square
- draw()
- erase()

Line
- draw()
- erase()

Useful
- void f()
- void q()

More Useful
- void f()
- void q()
- void u()
- void v()
- void w()
Composition Syntax

- Can also initialize in the constructor
- Flexibility: Can change objects at run time!
- “Has-A” relationship

```java
class MyNewClass {
    Foo x = new Foo();
    Bar y = new Bar();
    Baz z = new Baz();
    // ...
}
```
class Soap {
    private String s;
    Soap() {
        System.out.println("Soap()”);
        s = new String("Constructed");
    }
    public String toString() { return s; }
}

class Bath {
    private String
        // Initializing at point of definition:
s1 = new String("Happy"),
s2 = "Happy",
s3, s4;
    Soap castille;
    int i;
    float toy;
    Bath() {
        System.out.println("Inside Bath()”);
        s3 = new String("Joy");
        i = 47;
        toy = 3.14f;
        castille = new Soap();
    }
    void print() {
        // Delayed initialization:
        if(s4 == null)
            s4 = new String("Joy");
        System.out.println("s1 = " + s1);
        System.out.println("s2 = " + s2);
        System.out.println("s3 = " + s3);
        System.out.println("s4 = " + s4);
        System.out.println("i = " + i);
        System.out.println("toy = " + toy);
        System.out.println("castille = " + castille);
    }
    public static void main(String[] args) {
        Bath b = new Bath();
        b.print();
    }
}
Base interface automatically duplicated in derived classes

Base data members also duplicated

If a derived member is not redefined, base definition is used

class D1 extends B {
  public void f() {
    /* ... */
  }
}

Inheritance Syntax

class B {
  public void f(){
    /* ... */
  }
  public void g(){
    /* ... */
  }
}
class Cleanser {
    private String s = new String("Cleanser");
    public void append(String a) { s += a; }
    public void dilute() { append("dilute()"); }
    public void apply() { append("apply()"); }
    public void scrub() { append("scrub()"); }
    public void print() { System.out.println(s); }
    
    public static void main(String[] args) {
        Cleanser x = new Cleanser();
        x.dilute();
        x.apply();
        x.scrub();
        x.print();
    }
}

public class Detergent extends Cleanser {
    // Change a method:
    public void scrub() {
        append("Detergent.scrub()");
        super.scrub(); // Call base-class version
    }
    // Add methods to the interface:
    public void foam() { append("foam()"); }
    
    // Test the new class:
    public static void main(String[] args) {
        Detergent x = new Detergent();
        x.dilute();
        x.apply();
        x.scrub();
        x.foam();
        x.print();
        System.out.println("Testing base class:");
        Cleanser.main(args);
    }
}
Initializing the Base class

• Java automatically calls default constructors

```java
class Art {
    Art() {
        System.out.println("Art constructor");
    }
}
class Drawing extends Art {
    Drawing() {
        System.out.println("Drawing constructor");
    }
}
public class Cartoon extends Drawing {
    Cartoon() {
        System.out.println("Cartoon constructor");
    }
    public static void main(String[] args) {
        Cartoon x = new Cartoon();
    }
} ///:~
```
Constructors with Arguments

• Base constructor call must happen first
• Use `super` keyword

```java
class Game {
    Game(int i) {
        System.out.println("Game constructor");
    }
}

class BoardGame extends Game {
    BoardGame(int i) {
        super(i);
        System.out.println("BoardGame constructor");
    }
}

public class Chess extends BoardGame {
    Chess() {
        super(11);
        System.out.println("Chess constructor");
    }
    public static void main(String[] args) {
        Chess x = new Chess();
    }
} ///:~
```
Choosing Composition vs. Inheritance

- Inheritance is determined at compile time; member binding can be delayed until run time
- Member rebinding is possible
- In general, prefer composition to inheritance as a first choice

Car is an engine?
- NO!
- RIGHT

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Initialization with Inheritance

class Insect {
    int i = 9;
    int j;
    Insect() {
        prt("i = " + i + ", j = " + j);
        j = 39;
    }
    static int x1 =
       prt("static Insect.x1 initialized");
    static int prt(String s) {
        System.out.println(s);
        return 47;
    }
}

public class Beetle extends Insect {
    int k = prt("Beetle.k initialized");
    Beetle() {
        prt("k = " + k);
        prt("j = " + j);
    }
    static int x2 =
       prt("static Beetle.x2 initialized");
    public static void main(String[] args) {
        prt("Beetle constructor");
        Beetle b = new Beetle();
    }
} //://~

>>
static Insect.x1 initialized
static Beetle.x2 initialized
Beetle constructor
i = 9, j = 0
Beetle.k initialized
k = 47
j = 39
The final Keyword

• Slightly different meanings depending on context
• “This cannot be changed”
• A bit confusing: two reasons for using it
  – Design
  – Efficiency
• final fields
• final methods
• final class
final Fields

1) Compile-time constant
Must be given a value at point of definition

final static int NINE = 9;

May be “folded” into a calculation by the compiler

2) Run-time constant
Cannot be changed from initialization value

final int RNUM = (int)(Math.random()*20);

• final static: only one instance per class, initialized at the time the class is loaded, cannot be changed.
• final references: cannot be re-bound to other objects
final arguments & final Classes

• Final arguments
  – void f(final int i) { // ...
    • Primitives can’t be changed inside method
  – void g(final Bob b) { // ...
    • References can’t be rebound inside method
    • Generally, neither one is used

• Final Class
  – Cannot inherit from final class
  – All methods are implicitly final
  – Fields may be final or not, as you choose
final Methods

1) Put a “lock” on a method to prevent any inheriting class from overriding it (design)

2) Efficiency (try to avoid the temptation...)
   - Compiler has permission to “inline” a final method
     • Replace method call with code
     • Eliminate method-call overhead
   - Programmers are characteristically bad about guessing where performance problems are
   - Limits use of class (example: can’t override Vector)

• Private methods are implicitly final
Polymorphism

"Substitutability"

draw() → Shape
erase() → Shape

{ A Circle
A Square
A Line
}

"Extensibility"

draw() → Shape
erase() → Shape

{ A Circle
A Square
A Line
A Triangle
}
Implementations of the common interface

Shape \( s = \text{new Circle}(); \)
Why Upcast?

• All true OOP programs have some upcasting somewhere
• Upcasting allows us to isolate type specific details from the bulk of your code, i.e. decoupling
• Code is simpler to write and read
• Most important
  – Changes in type do not propagate changes in code
A problem

```java
Shape s = new Circle();
```

You might think `s.draw()` calls this `draw()` since `s` is a `Shape`.

We want it to call this `draw()` since `s` actually points to a `Circle`.
Dynamic Binding in Java

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class Shape {
    void draw() {}
    void erase() {}
}
class Circle extends Shape {
    void draw() {
        System.out.println("Circle.draw()");
    }
    void erase() {
        System.out.println("Circle.erase()");
    }
    System.out.println("Circle.draw()");
}
class Square extends Shape {
    void draw() {
        System.out.println("Square.draw()");
    }
    void erase() {
        System.out.println("Square.erase()");
    }
}
class Triangle extends Shape {
    void draw() {
        System.out.println("Triangle.draw()");
    }
    void erase() {
        System.out.println("Triangle.erase()");
    }
}

public class Shapes {
    public static Shape randShape() {
        switch((int)(Math.random() * 3)) {
            default: case 0: return new Circle();
            case 1: return new Square();
            case 2: return new Triangle();
        }
    }
}

public static void main(String[] args) {
    Shape[] s = new Shape[9];
    // Fill up the array with shapes:
    for(int i = 0; i < s.length; i++)
        s[i] = randShape();
    // Make polymorphic method calls:
    for(int i = 0; i < s.length; i++)
        s[i].draw();
    }
}
Extensibility

```
Instrument
  void play()
  String what()
  void adjust()

  Wind
  void play()
  String what()
  void adjust()

  Percussion
  void play()
  String what()
  void adjust()

  Stringed
  void play()
  String what()
  void adjust()

  Woodwind
  void play()
  String what()

  Brass
  void play()
  void adjust()
```
import java.util.*;

class Instrument {
    public void play() {
        System.out.println("Instrument.play()");
    }
    public String what() {
        return "Instrument";
    }
    public void adjust() {}  
}

class Wind extends Instrument {
    public void play() {
        System.out.println("Wind.play()");
    }
    public String what() { return "Wind"; }
    public void adjust() {}  
}

class Percussion extends Instrument {
    public void play() {
        System.out.println("Percussion.play()");
    }
    public String what() { return "Percussion"; }
    public void adjust() {}  
}

class Stringed extends Instrument {
    public void play() {
        System.out.println("Stringed.play()");
    }
    public String what() { return "Stringed"; }
    public void adjust() {}  
}

class Brass extends Wind {
    public void play() {
        System.out.println("Brass.play()");
    }
    public void adjust() {
        System.out.println("Brass.adjust()");
    }
}

class Woodwind extends Wind {
    public void play() {
        System.out.println("Woodwind.play()");
    }
    public String what() { return "Woodwind"; }
}

class Music3 {
    static void tune(Instrument i) {
        i.play();
    }
    static void tuneAll(Instrument[] e) {
        for(int i = 0; i < e.length; i++)
            tune(e[i]);
    }
    public static void main(String[] args) {
        Instrument[] orchestra = new Instrument[5];
        int i = 0;
        orchestra[i++] = new Wind();
        orchestra[i++] = new Percussion();
        orchestra[i++] = new Stringed();
        orchestra[i++] = new Brass();
        orchestra[i++] = new Woodwind();
        tuneAll(orchestra);
    }
}

Cities
class Wind extends Instrument {
    public void play() {
        System.out.println("Wind.play()");
    }
    public String what() { return "Wind"; }
    public void adjust() {}  
}

class Percussion extends Instrument {
    public void play() {
        System.out.println("Percussion.play()");
    }
    public String what() { return "Percussion"; }
    public void adjust() {}  
}

class Stringed extends Instrument {
    public void play() {
        System.out.println("Stringed.play()");
    }
    public String what() { return "Stringed"; }
    public void adjust() {}  
}

class Brass extends Wind {
    public void play() {
        System.out.println("Brass.play()");
    }
    public void adjust() {
        System.out.println("Brass.adjust()");
    }
}

class Woodwind extends Wind {
    public void play() {
        System.out.println("Woodwind.play()");
    }
    public String what() { return "Woodwind"; }
}

class Music3 {
    static void tune(Instrument i) {
        i.play();
    }
    static void tuneAll(Instrument[] e) {
        for(int i = 0; i < e.length; i++)
            tune(e[i]);
    }
    public static void main(String[] args) {
        Instrument[] orchestra = new Instrument[5];
        int i = 0;
        orchestra[i++] = new Wind();
        orchestra[i++] = new Percussion();
        orchestra[i++] = new Stringed();
        orchestra[i++] = new Brass();
        orchestra[i++] = new Woodwind();
        tuneAll(orchestra);
    }

    >>
    Wind.play()
    Percussion.play()
    Stringed.play()
    Brass.play()
    Woodwind.play()
Abstract classes & abstract methods

abstract Instrument
abstract void play();
String what() { /* ... */
abstract void adjust();

Cannot create instances

extends
extends
extends

Wind
void play()
String what()
void adjust()

Percussion
void play()
String what()
void adjust()

Stringed
void play()
String what()
void adjust()

Must define all abstract methods to create instances (or class is still abstract)

extends
extends

Woodwind
void play()
String what()

Brass
void play()
void adjust()
An abstract Instrument

- Some methods and data may be defined

```java
abstract class Instrument {
    int i; // storage allocated for each
    public abstract void play();
    public String what() {
        return "Instrument";
    }
    public abstract void adjust();
}
```

- Rest of the code is the same...
- This maps with C++, may have been an early design
Order of constructor calls

class Meal {
    Meal() { System.out.println("Meal()"); }
}

class Bread {
    Bread() { System.out.println("Bread()"); }
}

class Cheese {
    Cheese() { System.out.println("Cheese()"); }
}

class Lettuce {
    Lettuce() { System.out.println("Lettuce()"); }
}

class Lunch extends Meal {
    Lunch() { System.out.println("Lunch()");
    }
}

class PortableLunch extends Lunch {
    PortableLunch() {
        System.out.println("PortableLunch()");
    }
}

class Sandwich extends PortableLunch {
    Bread b = new Bread();
    Cheese c = new Cheese();
    Lettuce l = new Lettuce();
    Sandwich() {
        System.out.println("Sandwich()");
    }
}

public static void main(String[] args) {
    new Sandwich();
} ///:~
Order of Initialization

1) Base-class constructor is called
   This step is repeated recursively such that the very root of the hierarchy is constructed first, followed by the next derived class, etc., until the most derived class is reached

2) Member initializers are called in the order of declaration

3) Body of the derived-class constructor is called
Polymorphism & Constructors

• Inside constructor
  – Overridden method *is* used!

• This can produce incorrect results
  – Overridden method assumes all parts of derived class have been initialized
  – But you’re still in the base part of the constructor
  – Derived constructor hasn’t been called yet!
Pure Inheritance vs. Extension

“Is a”

Shape
- draw()
- erase()

Circle
- draw()
- erase()

Square
- draw()
- erase()

Line
- draw()
- erase()

“Subtyping”: re-using the interface
- Cannot extend the interface
- Allows full substitutability

Talks to Shape
message
→ Circle, Square, Line, or new type of Shape

“Is like a”

Useful
- void f()
- void g()

MoreUseful
- void f()
- void g()
- void u()
- void v()
- void w()

“Subclassing”: re-using the implementation.
- Prevents full substitutability

Talks to Useful object
message
→ Useful part

More useful part
Downcasting & Run-Time Type Identification (RTTI)

- Normally try to do everything with upcasting
- If you extend the class, you must downcast to access extended methods
- Java casts are always checked at run-time (safe)

```java
class Useful {
    public void f() {}
    public void g() {}
}

class MoreUseful extends Useful {
    public void f() {}
    public void g() {}
    public void u() {}
    public void v() {}
    public void w() {}
}

public class RTTI {
    public static void main(String args[]) {
        Useful x[] = {
            new Useful(),
            new MoreUseful()
        };
        x[0].f();
        x[1].g();
        // Compile-time: method not found in Useful:
        // x[1].u();
        ((MoreUseful)x[1]).u(); // Downcast/RTTI
        ((MoreUseful)x[0]).u(); // Exception thrown
    }
}
```
Summary

• Access control
  – What users can & can’t use (shows the area of interest)
  – Separating interface & implementation
  – Allowing the class creator to change the implementation later without disturbing client code
  – An important design & implementation flexibility

• Design guideline
  – Always make elements “as private as possible”
Summary Cont’d

• Easy to think that OOP is only about inheritance
• Often easier and more flexible to start with composition
  – Remember to say “has-a” and “is-a”
• Use inheritance when it’s clear that a new type is a kind of a base type
• Not just creating types, but proper behavior in all situations
• Allows decoupling of code from specific type it’s acting on: easy reading, writing & extensibility