A Second Look At Java

Subtype Polymorphism

```
Person x;
```

- Does this declare **`x`** to be a reference to an object of the **`Person`** class?
- Not exactly—the *type* **`Person`** may include references to objects of other classes
- Java has subtype polymorphism

Outline

- 15.2 Implementing interfaces
- 15.3 Extending classes
- 15.4 Extending and implementing
- 15.5 Multiple inheritance
- 15.6 Generics

Interfaces

- A method *prototype* just gives the method name and type—no method body
- An interface in Java is a collection of method prototypes

```
public interface Drawable {
  void show(int xPos, int yPos);
  void hide();
}
```

Implementing Interfaces

- A class can declare that it implements a particular interface
- Then it must provide **`public`** method definitions that match those in the interface

Examples

```
public class Icon implements Drawable {
  public void show(int x, int y) {
    … method body …
  }
  public void hide() {
    … method body …
  }
  …more methods and fields…
}
```

```
public class Square implements Drawable, Scalable {
 … all required methods of all interfaces implemented …
}
```

Why Use Interfaces?

- An interface can be implemented by many classes:

```
public class Window implements Drawable …
public class MousePointer implements Drawable …
public class Oval implements Drawable …
```

- Interface name can be used as a reference type:

```
Drawable d;
d = new Icon("i1.gif");
d.show(0,0);
d = new Oval(20,30);
d.show(0,0);
```

Polymorphism With Interfaces

```
static void flashoff(Drawable d, int k) {
  for (int i = 0; i < k; i++) {
    d.show(0,0);
    d.hide();
  }
}
```

- Class of object referred to by **`d`** is not known at compile time
- It is some class that **`implements Drawable`**, so it has **`show`** and **`hide`** methods that can be called

A More Complete Example

- A **`Worklist`** interface for a collection of **`String`** objects
- Can be added to, removed from, and tested for emptiness

```
public interface Worklist {
  /**
   * Add one String to the worklist.
   * @param item the String to add
   */
  void add(String item);

  /**
   * Test whether there are more elements in the
   * worklist:  that is, test whether more elements
   * have been added than have been removed.
   * @return true iff there are more elements
   */
  boolean hasMore();
  /**
   * Remove one String from the worklist and return
   * it.  There must be at least one element in the
   * worklist.
   * @return the String item removed
   */
  String remove();
}
```

Interface Documentation

- Comments are especially important in an interface, since there is no code to help the reader understand what each method is supposed to do
- **`Worklist`** interface does not specify ordering: could be a stack, a queue, or something else
- We will do an implementation as a stack, implemented using linked lists

```
/**
 * A Node is an object that holds a String and a link
 * to the next Node.  It can be used to build linked
 * lists of Strings.
 */
public class Node {
  private String data; // Each node has a String...
  private Node link;   // and a link to the next Node

  /**
   * Node constructor.
   * @param theData the String to store in this Node
   * @param theLink a link to the next Node
   */
  public Node(String theData, Node theLink) {
    data = theData;
    link = theLink;
  }
  /**
   * Accessor for the String data stored in this Node.
   * @return our String item
   */
  public String getData() {
    return data;
  }

  /**
   * Accessor for the link to the next Node.
   * @return the next Node
   */
  public Node getLink() {
    return link;
  }
}
```

```
/**
 * A Stack is an object that holds a collection of
 * Strings.
 */
public class Stack implements Worklist {
  private Node top = null; // top Node in the stack

  /**
   * Push a String on top of this stack.
   * @param data the String to add
   */
  public void add(String data) {
    top = new Node(data,top);
  }
  /**
   * Test whether this stack has more elements.
   * @return true if this stack is not empty
   */
  public boolean hasMore() {
    return (top!=null);
  }

  /**
   * Pop the top String from this stack and return it.
   * This should be called only if the stack is
   * not empty.
   * @return the popped String
   */
  public String remove() {
    Node n = top;
    top = n.getLink();
    return n.getData();
  }
}
```

A Test

```
Worklist w;
w = new Stack();
w.add("the plow.");
w.add("forgives ");
w.add("The cut worm ");
System.out.print(w.remove());
System.out.print(w.remove());
System.out.println(w.remove());
```

- Output: **`The cut worm forgives the plow.`**
- Other implementations of **`Worklist`** are possible: **`Queue`**, **`PriorityQueue`**, etc.

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More Polymorphism

- Another, more complex source of polymorphism
- One class can be derived from another, using the keyword **`extends`**
- For example: a class **`PeekableStack`** that is just like **`Stack`**, but also has a method **`peek`** to examine the top element without removing it

```
/**
 * A PeekableStack is an object that does everything a
 * Stack can do, and can also peek at the top element
 * of the stack without popping it off.
 */
public class PeekableStack extends Stack {

  /**
   * Examine the top element on the stack, without
   * popping it off.  This should be called only if
   * the stack is not empty.
   * @return the top String from the stack
   */
  public String peek() {
    String s = remove();
    add(s);
    return s;
  }
}
```

Inheritance

- Because **`PeekableStack`** extends **`Stack`**, it inherits all its methods and fields
- (Nothing like this happens with interfaces—when a class implements an interface, all it gets is an obligation)
- In addition to inheritance, you also get polymorphism

```
Stack s1 = new PeekableStack();
PeekableStack s2 = new PeekableStack();
s1.add("drive");
s2.add("cart");
System.out.println(s2.peek());
```

Note that **`s1.peek()`** is not legal here, even though **`s1`** is a reference to a **`PeekableStack`**. It is the static type of the reference, not the object's class, that determines the operations Java will permit.

Question

- Our **`peek`** was inefficient:

```
public String peek() {
  String s = remove();
  add(s);
  return s;
}
```

- Why not just do this?

```
public String peek() {
  return top.getData();
}
```

Answer

- The **`top`** field of **`Stack`** is **`private`**
- **`PeekableStack`** cannot access it
- For more efficient **`peek`**, **`Stack`** must make **`top`** visible in classes that extend it
- **`protected`** instead of **`private`**
- A common design challenge for object-oriented languages: designing for reuse by inheritance

Inheritance Chains

- A derived class can have more classes derived from it
- All classes but one are derived from some class
- If you do not give an **`extends`** clause, Java supplies one: **`extends Object`**
- **`Object`** is the ultimate base class in Java

The Class **`Object`**

- All classes are derived, directly or indirectly, from the predefined class **`Object`** (except **`Object`** itself)
- All classes inherit methods from **`Object`**:
  - **`toString`**, for converting to a **`String`**
  - **`equals`**, for comparing with other objects
  - **`hashcode`**, for computing an **`int`** hash code
  - etc.

Overriding Inherited Definitions

- Sometimes you want to redefine an inherited method
- No special construct for this: a new method definition automatically overrides an inherited definition of the same name and type

Overriding Example

```
System.out.print(new Stack());
```

- The inherited **`toString`** just combines the class name and hash code (in hexadecimal)
- So the code above prints something like:

```
Stack@b3d
```

- A custom **`toString`** method in **`Stack`** can override this with a nicer string:

```
public String toString() {
  return "Stack with top at " + top;
}
```

Inheritance Hierarchies

- Inheritance forms a hierarchy, a tree rooted at **`Object`**
- Sometimes inheritance is one useful class extending another
- In other cases, it is a way of factoring out common code from different classes into a shared base class

```java
public class Label {
  private int x,y;
  private int width;
  private int height;
  private String text;
  public void move
     (int newX, int newY)
  {
    x = newX;
    y = newY;
  }
  public String getText()
  {
    return text;
  }
}
```

```java
public class Icon {
  private int x,y;
  private int width;
  private int height;
  private Gif image;
  public void move
     (int newX, int newY)
  {
    x = newX;
    y = newY;
  }
  public Gif getImage()
  {
    return image;
  }
}
```

Two classes with a lot in common—but neither is a simple extension of the other.

```
public class Graphic {
  protected int x,y;
  protected int width,height;
  public void move(int newX, int newY) {
    x = newX;
    y = newY;
  }
}
```

```
public class Label
    extends Graphic {
  private String text;
  public String getText()
  {
    return text;
  }
}
```

```
public class Icon
    extends Graphic {
  private Gif image;
  public Gif getImage()
  {
    return image;
  }
}
```

Common code and data have been factored out into a common base class.

A Design Problem

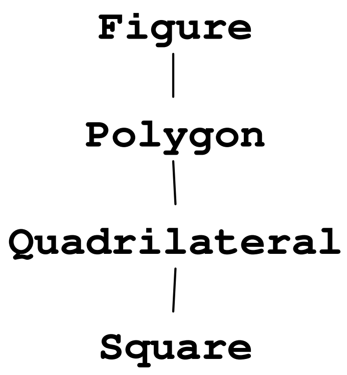
- When you write the same statements repeatedly, you think: that should be a method
- When you write the same methods repeatedly, you think: that should be a common base class
- The real trick is to see the need for a shared base class early in the design, before writing a lot of code that needs to be reorganized

Subtypes and Inheritance

- A derived class is a subtype
- From Chapter Six:

  A subtype is a subset of the values, but it can support a superset of the operations.

- When designing class hierarchies, think about inheritance of functionality
- Not all intuitively reasonable hierarchies work well for inheriting functionality



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Extending And Implementing

- Classes can use **`extends`** and **`implements`** together
- For every class, the Java language system keeps track of several properties, including:

A: the interfaces it implements
B: the methods it is obliged to define
C: the methods that are defined for it
D: the fields that are defined for it

Simple Cases For A Class

- A method definition affects C only
- A field definition affects D only
- An **`implements`** part affects A and B
  - All the interfaces are added to A
  - All the methods in them are added to B

A:	the interfaces it implements
B:	the methods it is obliged to define
C:	the methods that are defined for it
D:	the fields that are defined for it

Tricky Case For A Class

- An **`extends`** part affects all four:
  - All interfaces of the base class are added to A
  - All methods the base class is obliged to define are added to B
  - All methods of the base class are added to C
  - All fields of the base class are added to D

A: the interfaces it implements
B: the methods it is obliged to define
C: the methods that are defined for it
D: the fields that are defined for it

Previous Example

```
public class Stack implements Worklist {…}

public class PeekableStack extends Stack {…}
```

- `PeekableStack` has:
  - A: `Worklist` interface, inherited
  - B: obligations for `add`, `hasMore`, and `remove`, inherited
  - C: methods `add`, `hasMore`, and `remove`, inherited, plus its own method `peek`
  - D: field `top`, inherited

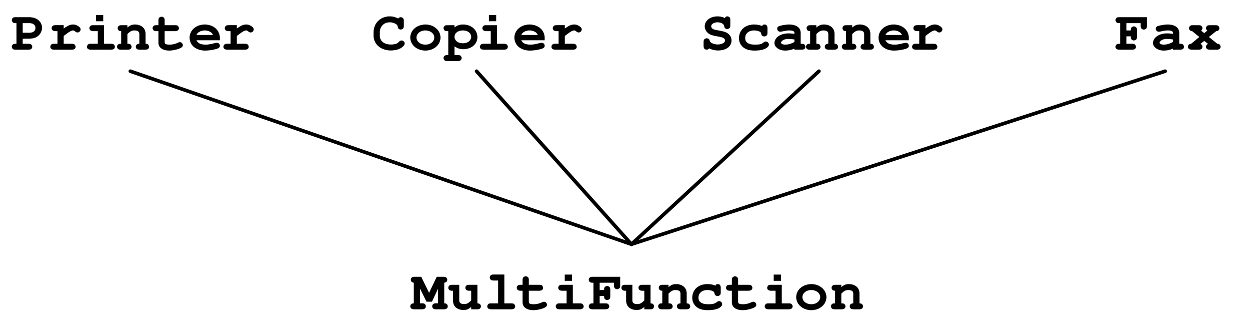
A Peek At **`abstract`**

- Note that C is a superset of B: the class has definitions of all required methods
- Java ordinarily requires this
- Classes can get out of this by being declared **`abstract`**
- An **`abstract`** class is used only as a base class; no objects of that class are created
- We will not be using **`abstract`** classes

Outline

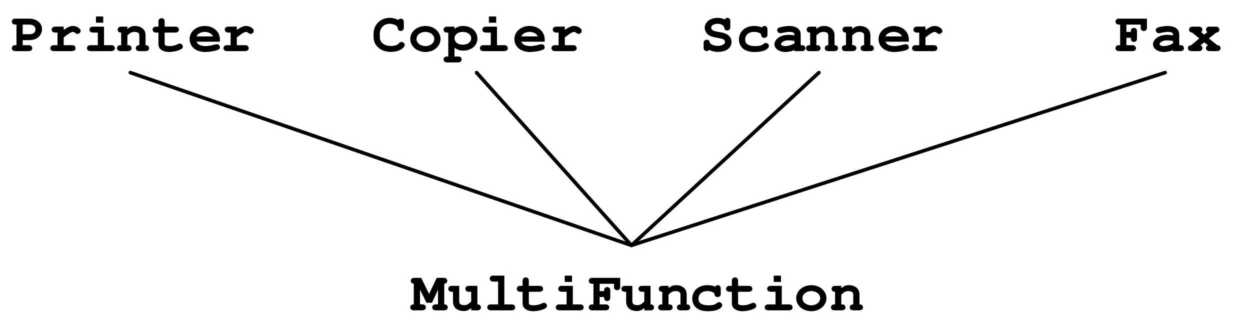
Multiple Inheritance

- In some languages (such as C++) a class can have more than one base class
- Seems simple at first: just inherit fields and methods from all the base classes
- For example: a multifunction printer



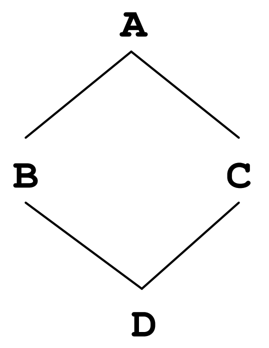
Collision Problem

- The different base classes are unrelated, and may not have been designed to be combined
- **`Scanner`** and **`Fax`** might both have a method named **`transmit`**
- When **`MultiFunction.transmit`** is called, what should happen?



Diamond Problem

- A class may inherit from the same base class through more than one path



- If **`A`** defines a field **`x`**, then **`B`** has one and so does **`C`**
- Does **`D`** get two of them?

Solvable, But…

- A language that supports multiple inheritance must have mechanisms for handling these problems
- Not all that tricky
- The question is, is the additional power worth the additional language complexity?
- Java’s designers did not think so

Living Without Multiple Inheritance

- One benefit of multiple inheritance is that a class can have several unrelated types (like **`Copier`** and **`Fax`**)
- This can be done in Java by using interfaces: a class can implement any number of interfaces
- Another benefit is inheriting implementation from multiple base classes
- This is harder to accomplish with Java

Forwarding

```
public class MultiFunction {
  private Printer myPrinter;
  private Copier myCopier;
  private Scanner myScanner;
  private Fax myFax;

  public void copy() {
    myCopier.copy();
  }
  public void transmitScanned() {
    myScanner.transmit();
  }
  public void sendFax() {
    myFax.transmit();
  }
  …
}
```

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An Early Weakness in Java

- Previous **`Stack`** example: a stack of strings
- Can’t be reused for stacks of other types
- In ML we used type variables for this:

```
datatype 'a node =
  NULL |
  CELL of 'a * 'a node;
```

- Ada and C++ have something similar, but Java originally did not

Living Without Generics

- Until the 2004 additions to Java, programmers had to work around this
- For example, we could have made a stack whose element type is **`Object`**
- The type **`Object`** includes all references, so this would allow any objects to be placed in the stack

```
public class ObjectNode {
  private Object data;
  private ObjectNode link;
  public ObjectNode(Object theData,
       ObjectNode theLink) {
    data = theData;
    link = theLink;
  }
  public Object getData() {
    return data;
  }
  public ObjectNode getLink() {
    return link;
  }
}
```

Similarly, we could define **`ObjectStack`** (and an **`ObjectWorklist`** interface) using **`Object`** in place of **`String`**

Weaknesses

- No compile-time type checking on the element types

```
ObjectStack s1 = new ObjectStack();
s1.add("hello");
s1.add(s1);
```

- Usually, that kind of code is an error, and programmers want the compiler to help identify it

Weaknesses

- To recover the type of the stacked object, we will have to use an explicit *type cast:*

```
ObjectStack s1 = new ObjectStack();
s1.add("hello");
String s = (String) s1.remove();
```

- This is a pain to write, and also inefficient
- Java checks at runtime that the type cast is legal—the object really is a **`String`**

Weaknesses

- Primitive types must first be stored in an object before being stacked:

```
ObjectStack s2 = new ObjectStack();
s2.add(new Integer(1));
int i = ((Integer) s2.remove()).intValue();
```

- Again, laborious and inefficient
- **`Integer`** is a predefined wrapper class
- There is one for every primitive type

True Generics

- In 2004, Java was extended
- It now has parameterized polymorphic classes, interfaces, methods, and constructors
- You can tell them by the distinctive notation using angle brackets after the type name

```
interface Worklist<T> {
  void add(T item);
  boolean hasMore();
  T remove();
}
```

formal *type parameter* defines a type variable **`T`** inside this interface

uses of the type variable **`T`**

```
Worklist<String> w;
…
w.add("Hello");
String s = w.remove();
```

actual *type parameter* when we use the type; now **`add`** takes a **`String`**, and **`remove`** returns a **`String`**

```
public class Node<T> {
  private T data;
  private Node<T> link;
  public Node(T theData, Node<T> theLink) {
    data = theData;
    link = theLink;
  }
  public T getData() {
    return data;
  }
  public Node<T> getLink() {
    return link;
  }
}
```

```
public class Stack<T> implements Worklist<T> {
  private Node<T> top = null;
  public void add(T data) {
    top = new Node<T>(data,top);
  }
  public boolean hasMore() {
    return (top!=null);
  }
  public T remove() {
    Node<T> n = top;
    top = n.getLink();
    return n.getData();
  }
}
```

Using Generic Classes

```
Stack<String> s1 = new Stack<String>();
Stack<Integer> s2 = new Stack<Integer>();
s1.add("hello");
String s = s1.remove();
s2.add(1);
int i = s2.remove();
```

- Notice the coercions: **`int`** to **`Integer`** ("boxing") and **`Integer`** to **`int`** ("unboxing")
- These also were added in 2004