CS61B Lectures #7:

- If you feel you can do the labs at home, make arrangements with your TA to get them checked off.

- Programming Contest: September 25th. Links are on our web page.

Abstract Methods and Classes

- Instance method can be *abstract:* No body *given;* must be supplied in subtypes.

- One good use is in specifying a pure interface to a family of types:

```
/** A drawable object. */
public abstract class Drawable {  // "abstract" = "can't say new Drawable"
   /** Expand THIS by a factor of SIZE */
   public abstract void scale (double size);
   /** Draw THIS on the standard output. */
   public abstract void draw ();
}
```

  Now a `Drawable` is something that has *at least* the operations `scale` and `draw` on it. Can't create a `Drawable` because it's abstract—in particular, it has two methods without any implementation.

- *BUT,* we can write methods that operate on `Drawables`:

```
void drawAll (Drawable[] thingsToDraw) {
    for (int i = 0; i < thingsToDraw.length; i += 1)
      thingsToDraw[i].draw ();
}
```

- But `draw` has no implementation! How can this work?

Concrete Subclasses

- Can define kinds of `Drawable`s that are non-abstract. To do so, must supply implementations for all methods:

```
public class Rectangle extends Drawable {
  public Rectangle (double w, double h) { this.w = w; this.h = h; }
  public void scale (double size) { w *= size; h *= size; }
  public void draw () { draw a w x h rectangle }
  private double w,h;
}
```

Any `Circle` or `Rectangle` is a Drawable.

```
public class Circle extends Drawable {
  public Circle (double rad) { this.rad = rad; }
  public void scale (double size) { rad *= size; }
  public void draw () { draw a circle with radius rad }
  double rad;
}
```

- So, writing

```
Drawable[] things = { new Rectangle (3, 4), new Circle (2) };
drawAll (things);
```

draws a 3×4 rectangle and a circle with radius 2.

Interfaces

- In generic use, an *interface* is a "point where interaction occurs between two systems, processes, subjects, etc." (*Concise Oxford Dictionary*).

- In programming, often use the term to mean a *description* of this generic interaction, specifically, a description of the functions or variables by which two things interact.

- Java uses the term to refer to a slight variant of an abstract class that contains only abstract methods (and static constants).

- Idea is to treat Java interfaces as the public specifications of data types, and classes as their implementations:

```
public interface Drawable {
  void scale (double size);   // Automatically public abstract.
  void draw ();
}


public class Rectangle implements Drawable { ... }
```

- **Interfaces are automatically abstract: can't say** new Drawable(); **can say** new Rectangle(...).

Multiple Inheritance

- Can *extend* one class, but *implement* any number of interfaces.

- Contrived Example:

```
interface Readable {              |    void copy (Readable r,
  Object get ();                  |              Writable w)
}                                 |    {
                                  |       w.put (r.get ());
                                  |    }
interface Writable {              |
  void put (Object x);            |
}                                 |
                                  |
class Source implements Readable { |  class Sink implements Writable {
  public Object get () { ... }    |    public void put (Object x) { ... }
}                                 |  }
```

```
         class Variable implements Readable, Writable {
           public Object get () { ... }
           public void put (Object x) { ... }
         }
```

- The first argument of `copy` can be a `Source` or a `Variable`. The second can be a `Sink` or a `Variable`.

Review: Higher-Order Functions

- In Scheme, you had *higher-order functions* like this (adapted from *SICP*)

```
(define (map    proc        items)
;               function    list
   (if (null? items)
        nil
        (cons (proc (car items)) (map proc (cdr items))))))
```

and could write

```
(map abs (list -10 2 -11 17))
   ====> (10 2 11 17)
(map (lambda (x) (* x x)) (list 1 2 3 4))
   ====> (1 4 9 16)
```

- Java does not have these directly, but can use abstract classes or interfaces and subtyping to get the same effect (with more writing)

Map in Java

```
/** Function with one integer argument */ |  IntList map (IntUnaryFunction proc,
                                          |                  IntList items) {
public interface IntUnaryFunction {       |    if (items == null)
  int apply (int x);                      |      return null;
}                                         |    else return new IntList (
                                          |        proc.apply (items.head),
                                          |        map (proc, items.tail)
                                          |      );
                                          |  }
```

- It's the use of this function that's clumsy. First, define class for absolute value function; then create an instance:

```
class Abs implements IntUnaryFunction {
  public int apply (int x) { return Math.abs (x); }
}
-------------------------------------------------
map (new Abs (), some list);
```

- Or, we can write a lambda expression (sort of):

```
map (new IntUnaryFunction () {
        public int apply (int x) { return x*x; }
      }, some list);
```

A Puzzle

```
class A {                                          | class B extends A {
  void f ()        { System.out.println ("A.f"); } |   void f ()           {
  void g () { f (); /* or this.f()  */ }           |     System.out.println ("B.f");
//static void g (A y) { y.f(); }                   |   }
}                                                  | }
```

```
        class C {
          static void main (String[] args) {
            B aB = new B ();
            h (aB);
          }

          static void h (A x) { x.g() }
          //static void h (A x) { A.g(x); } x.g(x) also legal here
        }
```

1. What is printed?

2. What if we made g static?

3. What if we made f static?

4. What if f were not defined in A?

Choices:

  a. A.f

  b. B.f

  c. Some kind of error

A Puzzle

```
class A {                                          | class B extends A {
  void f ()          { System.out.println ("A.f"); } |   void f ()          {
  void g () { f (); /* or this.f()  */ }            |     System.out.println ("B.f");
//static void g (A y) { y.f(); }                    |   }
}                                                   | }
```

```
        class C {
          static void main (String[] args) {
            B aB = new B ();
            h (aB);
          }

          static void h (A x) { x.g() }
          //static void h (A x) { A.g(x); } x.g(x) also legal here
        }
```

1. What is printed?

2. What if we made g static?

3. What if we made f static?

4. What if f were not defined in A?

Choices:

a. A.f

b. B.f

c. Some kind of error

A Puzzle

```
class A {                                          | class B extends A {
  void f ()          { System.out.println ("A.f"); } |   void f ()          {
//void g () { f (); /* or this.f()  */ }           |     System.out.println ("B.f");
  static void g (A y) { y.f(); }                   |   }
}                                                  | }
```

```
        class C {
          static void main (String[] args) {
            B aB = new B ();
            h (aB);
          }


        //static void h (A x) { x.g() }
          static void h (A x) { A.g(x); } x.g(x) also legal here
        }
```

1. What is printed?

2. What if we made g static?

3. What if we made f static?

4. What if f were not defined in A?

Choices:

a. A.f

b. B.f

c. Some kind of error

A Puzzle

```
class A {                                          | class B extends A {
  void f ()         { System.out.println ("A.f"); } |   void f ()          {
//void g () { f (); /* or this.f()  */ }           |     System.out.println ("B.f");
  static void g (A y) { y.f(); }                   |   }
}                                                  | }
```

```
        class C {
          static void main (String[] args) {
            B aB = new B ();
            h (aB);
          }


          //static void h (A x) { x.g() }
          static void h (A x) { A.g(x); } x.g(x) also legal here
        }
```

1. What is printed?

2. What if we made g static?

3. What if we made f static?

4. What if f were not defined in A?

Choices:

a. A.f

b. B.f

c. Some kind of error

A Puzzle

```
class A {                                              | class B extends A {
  static void f () { System.out.println ("A.f"); } |   static void f () {
  void g () { f (); /* or this.f()  */ }           |     System.out.println ("B.f");
//static void g (A y) { y.f(); }                   |   }
}                                                  | }
```

```
        class C {
          static void main (String[] args) {
            B aB = new B ();
            h (aB);
          }

          static void h (A x) { x.g() }
          //static void h (A x) { A.g(x); } x.g(x) also legal here
        }
```

1. What is printed?

2. What if we made g static?

3. What if we made f static?

4. What if f were not defined in A?

Choices:

a. A.f

b. B.f

c. Some kind of error

A Puzzle

```
class A {                                        | class B extends A {
  static void f () { System.out.println ("A.f"); } |   static void f () {
  void g () { f (); /* or this.f()  */ }            |     System.out.println ("B.f");
//static void g (A y) { y.f(); }                     |   }
}                                                 | }
```

```
        class C {
          static void main (String[] args) {
            B aB = new B ();
            h (aB);
          }

          static void h (A x) { x.g() }
          //static void h (A x) { A.g(x); } x.g(x) also legal here
        }
```

1. What is printed?

2. What if we made g static?

3. What if we made f static?

4. What if f were not defined in A?

Choices:

  a. A.f

  b. B.f

  c. Some kind of error

A Puzzle

```
class A {                                      | class B extends A {
                                               |   void f ()        {
 void g () { f (); /* or this.f()  */ }        |     System.out.println ("B.f");
//static void g (A y) { y.f(); }               |   }
}                                              | }
```

```
        class C {
          static void main (String[] args) {
            B aB = new B ();
            h (aB);
          }


          static void h (A x) { x.g() }
          //static void h (A x) { A.g(x); } x.g(x) also legal here
        }
```

1. What is printed?

2. What if we made g static?

3. What if we made f static?

4. What if f were not defined in A?

Choices:

  a. A.f

  b. B.f

  c. Some kind of error

A Puzzle

```
class A {                                    | class B extends A {
                                             |   void f ()          {
  void g () { f (); /* or this.f()  */ }     |     System.out.println ("B.f");
//static void g (A y) { y.f(); }             |   }
}                                            | }
```

```
        class C {
          static void main (String[] args) {
            B aB = new B ();
            h (aB);
          }


          static void h (A x) { x.g() }
          //static void h (A x) { A.g(x); }  x.g(x) also legal here
        }
```

1. What is printed?

2. What if we made g static?

3. What if we made f static?

4. What if f were not defined in A?

Choices:

a. A.f

b. B.f

c. Some kind of error

Answer to Puzzle

1. Executing `java C` prints ___, because

    1. `C.main` calls `h` and passes it `aB`, whose dynamic type is `B`.
    2. `h` calls `x.g()`. Since `g` is inherited by `B`, we execute the code for `g` in class `A`.
    3. `g` calls `this.f ()`. Now `this` contains the value of `h`'s argument, whose dynamic type is `B`. Therefore, we execute the definition of `f` that is in `B`.
    4. In calls to `f`, in other words, static type is ignored in figuring out what method to call.

2. If `g` were static, we see ___; selection of `f` still depends on dynamic type of `this`.

3. If `f` were static, would print ___ because then selection of `f` would depend on static type of `this`, which is `A`.

4. If `f` were not defined in `A`, we'd get _____.

Answer to Puzzle

1. Executing `java C` prints <u>B.f</u>, because

   1. `C.main` calls `h` and passes it `aB`, whose dynamic type is `B`.
   2. `h` calls `x.g()`. Since `g` is inherited by `B`, we execute the code for `g` in class `A`.
   3. `g` calls `this.f ()`. Now `this` contains the value of `h`'s argument, whose dynamic type is `B`. Therefore, we execute the definition of `f` that is in `B`.
   4. In calls to `f`, in other words, static type is ignored in figuring out what method to call.

2. If `g` were static, we see <u>B.f</u>; selection of `f` still depends on dynamic type of `this`.

3. If `f` were static, would print <u>A.f</u> because then selection of `f` would depend on static type of `this`, which is `A`.

4. If `f` were not defined in `A`, we'd get <u>a compile-time error</u>.

Example: Designing a Class

Problem: Want a class that represents histograms, like this one:

| 0.0–0.2 | 0.2–0.4 | 0.4–0.6 | 0.6–0.8 | 0.8–1.0 |
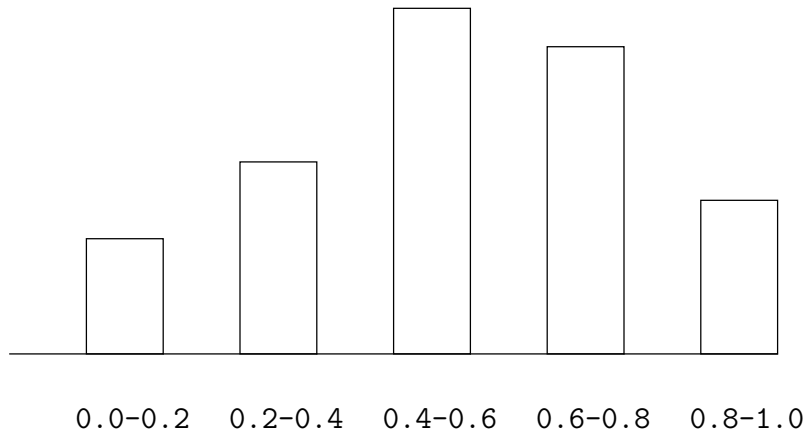
Analysis: What do we need from it? At least:

- Specify buckets and limits.

- Accumulate counts of values.

- Retrieve counts of values.

- Retrieve numbers of buckets and other initial parameters.

Specification Seen by Clients

- The *clients* of a module (class, program, etc.) are the programs or methods that *use* that module's exported definitions.

- In Java, intention is that exported definitions are designated **public**.

- Clients are intended to rely on *specifications*, not code.

- *Syntactic specification:* method and constructor headers—syntax needed to use.

- *Semantic specification:* what they do. No formal notation, so use comments.

  - Semantic specification is a *contract*.

  - Conditions client must satisfy (*preconditions*, marked "Pre:" in examples below).

  - Promised results (*postconditions*).

  - Design these to be *all the client needs!*

  - Exceptions communicate errors, specifically failure to meet preconditions.

Histogram Specification and Use

```java
/** A histogram of floating-point values */
public interface Histogram {
   /** The number of buckets in THIS. */
   int size ();


   /** Lower bound of bucket #K. Pre: 0<=K<size(). */
   double low (int k);


   /** # of values in bucket #K. Pre: 0<=K<size(). */
   int count (int k);


   /** Add VAL to the histogram. */
   void add (double val);
}
```

Sample output:

```
>=  0.00 |    10
>= 10.25 |    80
>= 20.50 |   120
>= 30.75 |    50
```

```java
void fillHistogram (Histogram H,
                    Scanner in)
{
   while (in.hasNextDouble ())
      H.add (in.nextDouble ());
}
```

```java
void printHistogram (Histogram H) {
   for (int i = 0; i < H.size (); i += 1)
      System.out.printf
         (">=%5.2f | %4d%n",
          H.low (i), H.count (i));
}
```

An Implementation

```java
public class FixedHistogram implements Histogram {
  private double low, high; /* From constructor*/
  private int[] count; /* Value counts */

  /** A new histogram with SIZE buckets recording values >= LOW and < HIGH. */
  public FixedHistogram (int size, double low, double high)
  {
    if (low >= high || size <= 0) throw new IllegalArgumentException ();
    this.low = low; this.high = high;
    this.count = new int[size];
  }

  public double low (int k) { return low + k * (high-low)/count.length; }

  public int count (int k) { return count[k]; }

  public void add (double val) {
      int k = (int) ((val-low)/(high-low) * count.length);
      if (k >= 0 && k < count.length) count[k] += 1;
  }
}
```

Let's Make a Tiny Change

Don't require *a priori* **bounds:**

```
class FlexHistogram implements Histogram {
  /** A new histogram with SIZE buckets. */
  public FlexHistogram (int size) {
    ?
  }
  // What needs to change?
}
```

- How would you do this? Profoundly changes implementation.

- But *clients* (like `printHistogram` and `fillHistogram`) still work with no changes.

- Illustrates the power of *separation of concerns*.

Implementing the Tiny Change

- Pointless to pre-allocate the `count` array.

- Don't know bounds, so must save arguments to `add`.

- Then recompute `count` array "lazily" when `count(···)` called.

- Invalidate `count` array whenever histogram changes.

```
class FlexHistogram implements Histogram {
    private List<Double> values = ...; // Java library type (later)
    int size;
    private int[] count;

    public FlexHistogram (int size) { this.size = size; this.count = null;  }

    public void add (double x) { count = null; values.add (x); }

    public int count (int k) {
      if (count == null) { compute count from values here.  }
      return count[k];
    }
}
```

Advantages of Procedural Interface over Visible Fields

By using public method for `count` instead of making the array `count` visible, the "tiny change" is transparent to clients:

- If client had to write `myHist.count[k]`, would mean

  "The number of items currently in the kth bucket of histogram `myHist` (and by the way, there is an array called `count` in `myHist` that always holds the up-to-date count)."

- Parenthetical comment *useless* to the client.

- But if `count` array had been visible, after "tiny change," *every use* of `count` in client program would have to change.

- So using a method for the public `count` decreases what client *has* to know, and (therefore) has to change.