Public Service Announcement:

- Upsilon Pi Epsilon (UPE), the CS honor society, holds tutoring and advising services for students. Friendly, courteous students who understand what you’re going through can help. For further information, go to http://upe.cs.berkeley.edu/services/tutoring
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:

```java
/** 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:

```java
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 Drawables that are non-abstract. To do so, must supply implementations for all methods:

  ```java
  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 \( w \times h \) 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 \( 3 \times 4 \) 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:

```java
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 {
    Object get ();
}

interface Writable {
    void put (Object x);
}

class Source implements Readable {
    public Object get () { ... }
}

class Sink implements Writable {
    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)

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

and could write

```scheme
(map abs (list -10 2 -11 17))
  ===> (10 2 11 17)
```

```scheme
(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 */
public interface IntUnaryFunction {
    int apply (int x);
}

IntList map (IntUnaryFunction proc, IntList items) {
    if (items == null)
        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 {
    void f () { System.out.println ("A.f"); }
    void g () { f (); /* or this.f() */ }
    //static void g (A y) { y.f(); }
}

class B extends A {
    void 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
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1. What is printed?
2. What if we made `g` static?
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Answer to Puzzle

1. Executing `java C` prints ___, because
   1. `C.main` calls `h` and passes it an `A`, 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 `B.f`, 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 `B.f`; selection of `f` still depends on dynamic type of `this`.

3. If `f` were static, would print `A.f` 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 a compile-time error.
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 pre-conditions.
/** 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);
}

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

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

    /** A new histogram with SIZE buckets recording values \(\geq\) 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 int size () { return count.length; }
    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.

```java
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 \( k^{\text{th}} \) 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.