Today:

- New in this lecture: the bare mechanics of “object-oriented programming.”
- The general topic is: Writing software that operates on many kinds of data.
Overloading

**Problem:** How to get `System.out.print(x)` to print `x`, regardless of type of `x`?

- In Scheme or Python, one function can take an argument of any type, and then test the type (if needed).
- In Java, methods specify a single type of argument.
- Partial solution: *overloading*—multiple method definitions with the same name and different numbers or types of arguments.

- E.g., `System.out` has type `java.io.PrintStream`, which defines

  ```java
  void println()  Prints new line.
  void println(String s)  Prints S.
  void println(boolean b)  Prints "true" or "false"
  void println(char c)  Prints single character
  void println(int i)  Prints I in decimal
  ```

- Each of these is a different function. Compiler decides which to call on the basis of the arguments’ declared types.
**Generic Data Structures**

**Problem:** How to get a “list of anything” or “array of anything”?

- Again, no problem in Scheme or Python.
- But in Java, lists (such as `IntList`) and arrays have a single type of element.
- First, the short answer: any reference value can be cast as (converted to) type `Object` and back, so we can use `Object` as the “generic (reference) type.” Such reference casts don’t change the value of a pointer, but rather tell the compiler how to treat it:

```java
Object[] things = new Object[2];
things[0] = new IntList(3, null);
things[1] = "Stuff";
IntList thingsList = (IntList) things[0]; // A cast to IntList
// Both ((IntList) things[0]).head and thingsList.head == 3;
// and ((String) things[1]).startsWith("St") is true, BUT
// things[0].head Illegal
// things[1].startsWith("St") Illegal
```
And Primitive Values?

- Primitive values (ints, longs, bytes, shorts, floats, doubles, chars, and booleans) are not really convertible to `Object`.
- Presents a problem for “list of anything.”
- So Java introduced a set of reference types called wrapper types, one for each primitive type:

```
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>byte Byte</td>
<td>short Short</td>
<td>int Integer</td>
</tr>
<tr>
<td>long Long</td>
<td>char Character</td>
<td>boolean Boolean</td>
</tr>
<tr>
<td>float Float</td>
<td>double Double</td>
<td></td>
</tr>
</tbody>
</table>
```

- One can create new wrapper objects for any value (boxing):
  ```java
  Integer Three = new Integer(3);
  Object ThreeObj = Three;
  ```

  and vice-versa (unboxing):
  ```java
  int three = Three.intValue();
  ```
Autoboxing

Boxing and unboxing are automatic (in many cases):

```java
Integer Three = 3;
int three = Three;
int six = Three + 3;

Integer[] someInts = {1, 2, 3};
for (int x : someInts) {
    System.out.println(x);
}

System.out.println(someInts[0]);
    // Prints Integer 1, but NOT unboxed.
```
Dynamic vs. Static Types

• Every value has a type—its dynamic type.

• Every simple container (variable, component, parameter), every literal, function call, and operator expression (e.g. \( x+y \)) has a type—its static type.

• Therefore, every expression has a static type.

• The static type of an expression is known to the compiler.

• The specific dynamic type of the expression—the type of its value—is generally unknown to the compiler for reference types.

• But as we shall see, the compiler has some knowledge about the dynamic type of an expression because there is a relationship to the static type of the expression.
Examples of Static and Dynamic Types

```java
Object[] things = new Object[2];
things[0] = new IntList(3, null);
things[1] = "Stuff";
```

![Diagram showing examples of static and dynamic types]

- **Static type**: IntList
- **Dynamic type**: String
- **Value**: 3, null, "Stuff"

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Type Hierarchies

- A container with (static) type T may contain a certain value only if that value “is a” T—that is, if the (dynamic) type of the value is a **subtype** of T. Likewise, a function with return type T may return only values that are subtypes of T.
  
  - All types are subtypes of themselves (and that’s all for primitive types)
  - **Reference types** form a **type hierarchy**; some are subtypes of others.
  - **null**’s type is a subtype of all reference types.
  - All reference types are subtypes of Object.
Java Library Type Hierarchy (Partial)

int double boolean ... Object

Integer Double Boolean String IntList int[] Object[]

(is a)

(String is a IntList)

(un)wraps to

<String[]>

<nulltype>
The Basic Static Type Rule

- Java is designed so that an expression of (static) type T always yields a value that “is a” T.

- Static types are “known to the compiler,” because you declare them, as in

  ```java
  String x;        // Static type of field
  int f(Object s) { // Static type of call to f, and of parameter
    int y;         // Static type of local variable
  }
  ```

  or they are pre-declared by the language (like int).

- Compiler insists that in `L = E`, or in the function call, `f(E)`, where

  ```java
  void f(SomeType L) { ... }
  ```

  `E`’s static type must be a subtype of `L`’s static type for reference types.

- Similarly, there are static-type requirements for other operations:
  (1) `E` must have an array type in `E[i]`;
  (2) in `if (B) ...`, `B` must be boolean;
  or (3) in `E.x`, `E`’s static type must define a member named `x`; etc.
Primitive Types and Coercions

• Primitive types live outside the hierarchy of reference types.

• Although the values of type short, for example, are a subset of those of int, we don’t say that short is a subtype of int, because they don’t quite behave the same.

• However, values of type short can be coerced (converted) to a value of type int, using the same cast syntax as for reference types:

```java
short x = (short) 3002;
long y = 10000L;
int z = (int) y;
long q = 1000000000000L;
int r = (int) q;
System.out.println(r);  // Prints -727379968 (?????)
```

• As the values of r shows, coercions of primitive types, unlike those of reference types, are computations that can change values.
Automatic Coercions, Promotions

• Certain coercions, such converting from short to int, are considered obvious and therefore intrusive.

• So the language silently coerces “smaller” integer types to larger ones, float to double, and integer types to float or double.

• These are called promotions.

• Finally, since the compiler can obviously tell what the value of an int literal is, it will convert integer literals to shorter integer types if the values fit:

```java
byte x = 127;
short y = -1024;
char z = 0x0398;  // Θ
```
Consequences of Compiler’s “Sanity Checks”

- These are a conservative rules. The last line of the following, which you might think is perfectly sensible, is illegal:

```java
int[] A = new int[2];
Object x = A; // All references are Objects
A[i] = 0; // Static type of A is array...
x[i+1] = 1; // But not of x: ERROR
```

Compiler figures that not every Object is an array.

- Q: Don’t we know that x contains array value!?
- A: Yes, but still must tell the compiler, like this:

```java
((int[]) x)[i+1] = 1;
```

- Defn: Static type of cast (T) E is T.
- Q: What if x isn’t an array value, or is null?
- A: For that we have runtime errors—exceptions.
Overriding and Extension

• Notation so far is clumsy.

• Q: If I know Object variable \(x\) contains a String, why can’t I write, \(x\).startsWith("this")?

• A: \texttt{startsWith} is only defined on Strings, not on all Objects, so the compiler isn’t sure it makes sense, unless you cast.

• But, if an operation \texttt{were} defined on all Objects, then you \texttt{wouldn’t} need clumsy casting.

• Example: \texttt{.toString()} is defined on all Objects. You can always say \(x\).toString() if \(x\) has a reference type.

• The default \texttt{.toString()} function is not very useful; on an \texttt{IntList}, would produce string like "IntList@2f6684"

• But for any subtype of Object, you may \texttt{override} the default definition.
Overriding toString

• For example, if \( s \) is a String, \( s\.toString() \) is the identity function (fortunately).

• For any type you define, you may supply your own definition. For example, in IntList, could add

```java
@Override    // Compiler checks that Object really has a toString.
public String toString() {
    StringBuffer b = new StringBuffer();
    b.append("[");
    for (IntList L = this; L != null; L = L.tail)
        b.append(" " + L.head);
    b.append("]");
    return b.toString();
}
```

• If \( x = \text{new IntList}(3, \text{new IntList}(4, \text{null})) \), then \( x\.toString() \) is "[3 4]."

• Conveniently, various operations requiring Strings call .toString() for you, so for an IntList \( x \), you can write:

```
"Values: " + x, System.out.println(x), or System.out.printf("%s",x);
```
Extending a Class

• To say that class B is a direct subtype of class A (or A is a direct superclass of B), write

   class B extends A { ... }

• By default, class ... extends java.lang.Object.

• The subtype inherits all fields and methods of its direct superclass (and passes them along to any of its subtypes).

• In class B, you may override an instance method (not a static method), by providing a new definition with same signature (name, return type, argument types).

   Rule of Instance Method Calls:

   If f(...) is an instance method, then the call x.f(...) calls whatever overriding of f applies to the dynamic type of x, regardless of the static type of x.
Illustration

class Worker {
    void work() {
        collectPay();
    }
}

class Prof extends Worker {
    // Inherits work()
}

class TA extends Worker {
    void work() {
        while (true) {
            doLab(); discuss(); officeHour();
        }
    }
}

Prof paul = new Prof();  // paul.work() ==> collectPay();
TA daniel = new TA();     // daniel.work() ==> doLab(); discuss(); ...
Worker wPaul = paul,      // wPaul.work() ==> collectPay();
    wDaniel = daniel;     // wDaniel.work() ==> doLab(); discuss(); ...

Lesson: For instance methods (only), select method based on dynamic type. Simple to state, but we’ll see it has profound consequences.
What About Fields and Static Methods?

class Parent {
    int x = 0;
    static int y = 1;
    static void f() {
        System.out.printf("Ahem!\n");
    }
    static int f(int x) {
        return x+1;
    }
}

class Child extends Parent {
    String x = "no";
    static String y = "way";
    static void f() {
        System.out.printf("I wanna!\n");
    }
}

Child tom = new Child();
Parent pTom = tom;

<table>
<thead>
<tr>
<th>tom.x</th>
<th>pTom.x</th>
</tr>
</thead>
<tbody>
<tr>
<td>no</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>tom.y</th>
<th>pTom.y</th>
</tr>
</thead>
<tbody>
<tr>
<td>way</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>tom.f()</th>
<th>pTom.f()</th>
</tr>
</thead>
<tbody>
<tr>
<td>I wanna!</td>
<td>Ahem!</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>tom.f(1)</th>
<th>pTom.f(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Lesson: Fields hide inherited fields of same name; static methods hide methods of the same signature.

Real Lesson: Hiding causes confusion; so understand it, but don’t do it!
What's the Point?

• The mechanism described here allows us to define a kind of *generic* method.

• A superclass can define a set of operations (methods) that are common to many different classes.

• Subclasses can then provide different implementations of these common methods, each specialized in some way.

• All subclasses will have at least the methods listed by the superclass.

• So when we write methods that operate on the superclass, they will automatically work for all subclasses with no extra work.