# CS321 Languages and Compiler Design I

Winter 2012

Lecture 2

# A (Re-)Introduction to Java for C++/C Programmers

**Why Java?**

- Developed by Sun Microsystems (now Oracle) beginning in 1995.
- Conceived as a better, simpler version of C++.
- Imitated by C#.

**Notable Characteristics**

- Supports object-oriented programming.
- Strong static type safety.
- Garbage collection; strong memory security at runtime.
- Highly portable, via bytecode intermediate representation.

**Why Java in this course?**

- Good choice for project: higher level than C, but simpler than C++.
- Good choice for study of languages: modern, well-designed, widely used.

# Learning a Language: Resources

Sun documentation URL (for version 1.7):
`http://docs.oracle.com/javase`

**Textbooks and Tutorials**

- Arnold, Gosling, Holmes *The Java Programming Language, 4th ed.* (book)
- Eckel, *Thinking in Java, 4th ed.* (book or on web – see course syllabus)
- Many, many other books...
- Vendor's Java tutorials, on web at Oracle.

**Language and Library Specifications**

- *Java Language Specification, 3rd. ed.*, (on web at Oracle) (Very hard reading!)
- *Java Platform API Specification* (version-specific; on web at Oracle)

**Users manuals for Implementation**

- *Java JDK Tools and Utilities* (version-specific; on web at Oracle)

# JAVA VERSIONS

Language has had several revisions, usually identified by Oracle's JDK version numbers.

- Currently at version 1.7 (approximately; depends on platform)
- Last major language changes occured at 1.5.
- Course will assume 1.6; doesn't matter too much which exact version you use, as long as it 1.6 or later.
- Confusingly, Sun/Oracle sometimes refer to version 1.$n$ as **Java** $n$.

# Primitive Types: Numerics

A small collection of types are completely "built-in."

• **Integral types** (sizes same on **all** platforms):

`byte` (8 bits, signed)
`short` (16 bits, signed)
`int` (32 bits, signed)
`long` (64 bits, signed)
`char` (16 bits, unsigned – uses Unicode representations)

Integer arithmetic is always performed in 32 bits, unless a `long` operand is involved, in which case it is done in 64 bits. Values of smaller sizes are automatically promoted to larger ones where needed, but conversions the other way require explicit casts, e.g.,

```
short c;
short d = (short) (c+1);
```

• **Floating-point types** are `float` (32 bits) and `double` (64 bits) in IEEE format.

# Primitive Type: Boolean

Booleans are **not** integers! They form a distinct type `boolean` with two literal values `true` and `false`.

Boolean operators are the same as in C/C++, except that you cannot do arithmetic on boolean values. Booleans are used to govern `if`, `for`, `do`, and `while` statements as usual.

# DECLARATIONS

Declaring variables of primitive types is roughly as in C/C++, but:

• Compiler must be able to convince itself that all variables have been assigned a value before they are used, e.g.:

```
int i;
int j = 0;
if (j == 0)  // always true, but
  i = 1;     //  compiler doesn't know that!
i = i + 1;   // compile-time error!
```

Simple approach: always initialize variables in declarations!

• There are no `const` declarations, but variables can be declared `final`, which means that they can only be assigned to once, e.g.,:

```
final int j = 0; // j is constant
final int i;
i = 100;   // i is constant from now on
i = i + 1; // compile-time error!
```

## Expressions and Statements

These are mostly the same as in C and C++.

One difference: Java has no `goto` statement. (But you never use that anyway, right?)

Instead, it has a labeled `break` statement, which jumps to the end of labeled enclosing control structure (`for`, `while`, `do`, or `switch`). Unlabeled `break` jumps to the end of the innermost enclosing control structure, as usual. For example...

# Break Example

The code

```
    int i = 0;
  outer:
    while (true) {
      System.out.print (i);
      switch (i) {
      case 0:
        i++;    // falls through
      case 1:
        i += 2;
        break;  // break out of switch
      case 3:
        break outer; // break out of while
      }
    }
    System.out.print (99);
```

prints 0 3 99.

# OBJECTS

**Every** value in Java that does not belong to a primitive type is an **object**.

Each object is an **instance** of some **class**, which is much like a C++ class. Each class definition can contain **fields** and **methods** (i.e., functions). **Constructors** are a special kind of method used to create new instances; they typically initialize the values of the fields.

Each instance object contains its own copy of the field contents (ordinarily – more below!)

As in C++, methods (including the constructor method) can refer to the fields of the object for which they were invoked. Unless specifically restricted, fields can also be read or written from outside the class definition. (There are several possible kinds of restrictions; the details are similar but not identical to C++.)

An example using objects....

```
// A class to represent points in the plane
class Point {
  // Fields contain the point's coordinates
  int x;
  int y;

  // Constructor for creating points
  Point (int xInit, int yInit)  {
    x = xInit; y = yInit;
  }

  // Method on points
  void translateX (int deltaX) {
    x += deltaX;
  }
}
...
Point p = new Point(3,4);  // create new point object in p
p.translateX(7); // use method to change fields inside object
int x = p.x + p.y  // extract current values of fields (x = 14)
```

# Objects Live at Abstract Locations in the Heap

Objects are always* **heap-allocated**, i.e., `new` acts much like in C++.

Objects are **never** explicitly deallocated. Instead, the Java runtime system **automatically** deallocates them when they are no longer pointed to from anywhere in the running program.

This feature is called **garbage collection**. It has the huge advantage that the programmer doesn't have to worry about deallocation, and can't introduce **dangling pointers** (pointers that still point to deallocated objects) or **space leaks** (objects that are still allocated but no longer pointed to).

Also, object addresses are **abstract**; you can't do pointer arithmetic on them. (This is crucial for maintaining memory safety.)

(* Well, almost always. Clever compilers may be able to avoid the cost of heap allocation in certain special cases. Since addresses are abstract, you can't really tell.)

# Object Values are References

Variables of object type (like `p` above) **always** contain **references** (or pointers) to objects, rather than objects themselves. That is, the Java declaration

```
Point p;
```

is like the C++ declaration

```
Point *p;
```

Similarly, the Java notation

```
p.x
```

corresponds to the C++ notations

```
(*p).x
p->x
```

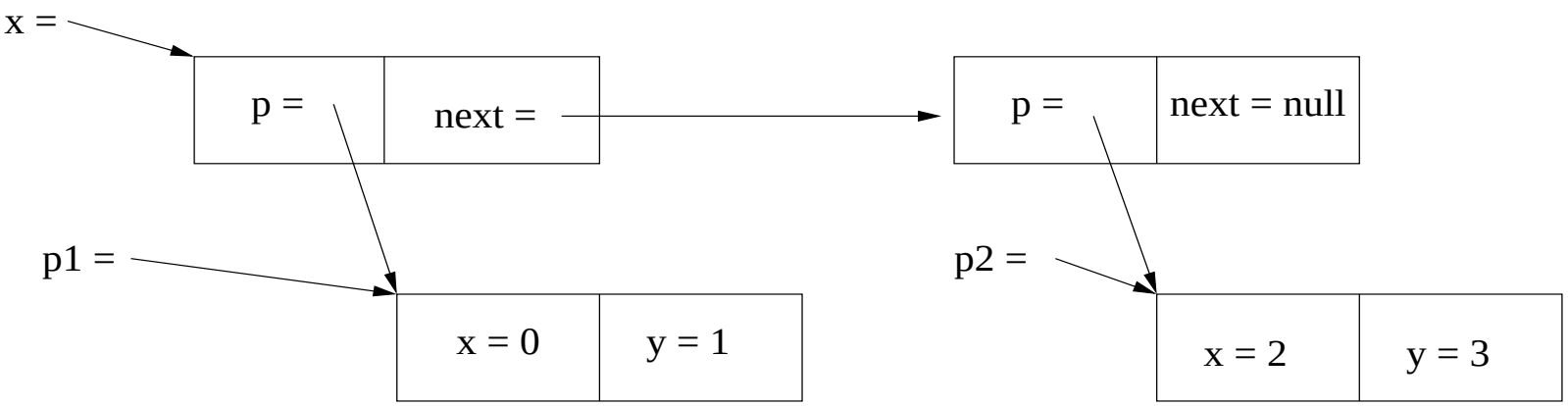
Unlike in C++, there is simply no way to declare storage for the object itself (e.g., on the stack, or inside another object). This is because fixed-size storage doesn't work well for object-oriented programming...

# Example of References

```
class Link {
  Point p;
  Link next;
  Link (Point pInit, Link nextInit) {
    p = pInit; next = nextInit;
  }
}
Point p1 = new Point(0,1);
Point p2 = new Point(2,3);
Link x = new Link(p1, new Link (p2, null));
```

Since both fields in `Link` are really references (pointers), the representation of `x` in the heap looks like...

# Example of References (continued)




Note that the special value `null`, representing an “empty” or “missing” object, is a legal value for all class types.

## COPYING IS SHALLOW

It is crucial to remember that **assigning** an object variable just assigns a pointer.

```
Point p1 = new Point(0,1);
Point p2 = p1; // p1, p2 point to same object
p1.x = 2;      // now p2.x == p1.x == 2
```

To copy the **contents** of an object, we must copy the individual fields one at a time. In Java this is called **cloning**.

# STATIC MEMBERS AND METHODS

Both fields and methods of a class can be declared **static**.

```
class Stuff {
  static int counter = 0;
  static int sqr(int x) { return x * x; }
} ...
Stuff.counter++;
int z = Stuff.sqr(33);
```

A **static field** has only one copy, no matter how many objects of the class are created. In effect, it is like a global variable.

A **static method** has no associated object; it operates only on its arguments (and possibly static fields from its own class or other classes).

Both static fields and methods are named using the dot notation, just as in ordinary field and method references. But for static members, the class name is what appears before the dot, rather than an expression that identifies an object. In fact, the semantics of static and non-static members are very different, so the similarity in notation for accessing them can lead to confusion.

# CLASSES WITHOUT INSTANCES

Many classes contain both static and non-static members, but some classes contain **only** static members. Such classes are never used to create instances (there would be no point, since the instances would contain no data); they just serve to organize the name space of top-level global variables and functions.

Example: the **System** class defined in the Java library contains useful top-level things, like

```
static PrintStream out; // standard output
```

which we can use to print things to the terminal, using the (non-static) methods defined on `PrintStream`, e.g.

```
System.out.println("hello world");
```

# FUNCTIONS ARE METHODS

Unlike in C++, **all** functions in a Java program are class methods (possibly `static`).

All arguments are passed **by value** just as in C. However, remember that object argument **values** are in fact **references**. For example:

```
class Foo {
  static void foo(Point p) {
    p.x = 0;
  }
}
...
Point p = new Point(10,20);
Foo.foo(p);
// p.x  now = 0
```

If a method has a non-`void` return type (primitive or class), the compiler must be able to convince itself that **all** possible paths through the function lead to a `return` statement with a value of appropriate type.

# OVERLOADING

A single class can define multiple methods with the same name, provided that their arguments are of different types. Such methods are said to be **overloaded**. The choice of which method will be called is made at **compile time**, based on the types of the actual arguments provided at the call site.

```
class Foo {
  static int foo(int i) { return 0; }
  static int foo(double d) { return 1; }
}
...
Foo.foo(3) + Foo.foo(3.14)
   // evaluates to 0 + 1 = 1
```

Methods cannot be overloaded based on return type.

# STRINGS

• Strings are (almost ordinary) objects of library class **String**. They are **immutable**, i.e., their contents can never change. We can use class member functions to access characters inside string.

• There is a another library class **StringBuilder** (or **StringBuffer**) for handling mutable sequences of characters.

• Strings are **not** arrays of characters.

Special language-level support for strings:

• Literal string constructors: `"abc"` creates a new `String` object.

• Applying the `+` operator to a string acts like string concatenation, e.g.,

```
String c = "abc" + "def"
```

makes `c` a new 6-character string object. This is actually turned into:

```
String c = new StringBuffer().append("abc").
                              append("def").toString()
```

Since `StringBuffer().append` is overloaded on all the primitive types, we can write things like: `"2+2=" + (2+2) // produces string "2+2=4"`

# ARRAYS

- Arrays are (slightly special) objects!
- Each array contains elements of some primitive type or class, e.g., `int[]`, `char[]`, `String[]`, `int[][]`.
- For compatibility with C/C++, can declare array variables in two equivalent ways:

```
int[] a; int a[];
```

- As with other objects, an array variable is just a **reference** to an array; to create the actual array (with contents) we must use `new`

```
int[] a = new int[10];
```

or an explicit initializer

```
int[] a = {1,2,3,4,5,6,7,8,9,10}
```

## ARRAYS (CONTINUED)

- The length of an array is fixed forever when the array is created; it can be retrieved using the built-in final instance variable `length`.
- All loads and stores on the array are checked against the array bounds; out-of-bounds index causes an exception to be raised.
- As in C/C++, multi-dimensional arrays are just one-dimensional arrays containing arrays as elements.

# Array Example

```
static double[] vAdd (double[] v1, double[] v2) {
  double[] r = new double[v1.length];
  for (int i = 0; i < v1.length; i++)
    r[i] = v1[i] + v2[i];
    return r;
  }

public static void main(String[] argv) {
  double a[] = {1.1,2.2,3.3};
  double b[] = vAdd (a,new double [] {4.4,5.5,6.6});
  ...
}
```

# PACKAGES

The **package** is Java's top-level code structuring mechanism.

- A package is just a namespace containing the definitions of one or more classes.
- Packages can include Sun's own library, other vendors' libraries, and your own local code.
- Important library packages include `java.lang`, `java.util`, and `java.io`.

# PACKAGES (CONTINUED)

• To refer to elements of a package, you can use **fully qualified names**, e.g.,

```
java.util.LinkedList myList =
   new java.util.LinkedList();
```

• Better: `import` the package name (or specific class names) that you need:

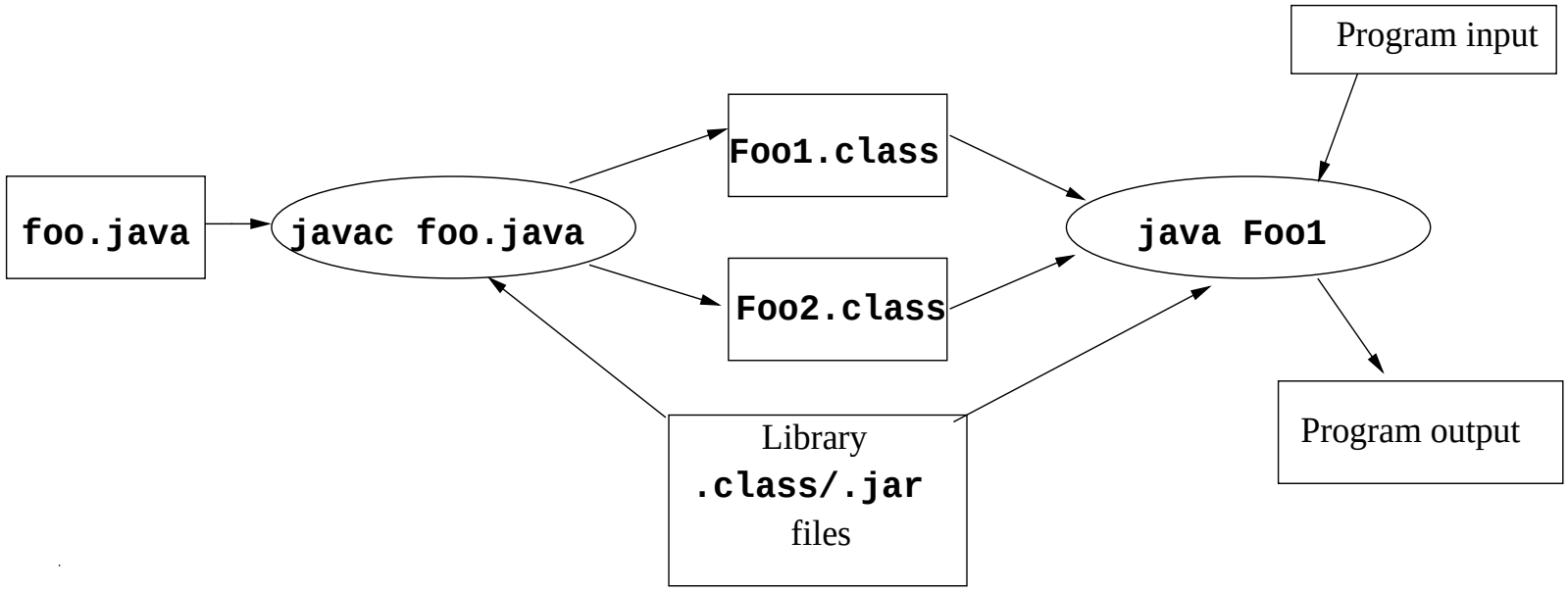
```
import java.util.*;  // at top of file
...
LinkedList myList = new LinkedList();
```

• Package `java.lang` is always implicitly imported, so you never need to qualify its class names.

• By default, classes **you** define go into a default anonymous package, which is fine for now.

# JAVA SYSTEM ARCHITECTURE

Standard Sun JDK set-up for building Java applications:




- Source file (`.java` extension) contains one or more class definitions.
- Use compiler executable (`javac`) to compile the source file into **byte-code** files (`.class` extension). (You get one `.class` file for each defined class. Name depends on class name, not on `.java` file name.)

# ARCHITECTURE (CONTINUED)

• Byte-codes are an intermediate format that must be executed by a **Java virtual machine (JVM)** executable (`java`). You must specify the name of the class (**without** `.class` extension!) containing desired `main` method (more below).

• JVM may interpret byte-codes directly, or may internally compile them to machine code and then execute that code. Much more about this later...

• Both `javac` and `java` access library packages (in standard location you don't have to specify) to get executable code and also static typing information (equivalent of C `.h` file info). Library may be in `.class` or `.jar` (Java archive) files.

• Both `javac` and `java` read and write in your current directory.

• You can direct them to look for input files in other directories by setting your **classpath**, either using the shell variable `CLASSPATH` or via a flag. For now, you should make sure the `CLASSPATH` variables is **NOT** set; some other packages on PSU CS may set it incorrectly.

# MAIN PROGRAM

Historically, Java programs came in two flavors:

**Applets** are intended to be run under the control of a browser (e.g., Netscape). These are largely *passé*.

**Applications** are stand-alone programs intended to be run directly by O/S (just like C or C++ executables).

We'll only be concerned with applications.

Every application must define some class with a method having this signature:

```
public static void main(String[] argv)
```

(where the argument name must be present, but is arbitrary).

When the application starts up, `main` is invoked with the argument set to an array containing the command line parameters.

# EXAMPLE

Suppose file `myapp.java` contains the following (complete) program

```
class MyApp {
  public static void main(String [] argv) {
    for (int i = 0; i < argv.length; i++)
        System.out.println(argv[i]);
  }
}
```

This can be compiled to bytecode as follows:

```
% javac myapp.java
%
```

This produces a file `MyApp.class`, which can be executed thus:

```
% java MyApp p d q
p
d
q
%
```

## More to Come

There are many important features of Java still to describe, including:

- Class inheritance and dynamic method dispatch.
- Utility collection classes, interfaces, polymorphism and generics.
- Exceptions.
- Iterators.

We will begin studying these by example in the next lecture.