Programming Languages and Techniques (CIS120)

Lecture 21

Transition to Java

Chapters 19 & 20

Goodbye OCaml…
…Hello Java!

Smoothing the transition to Java

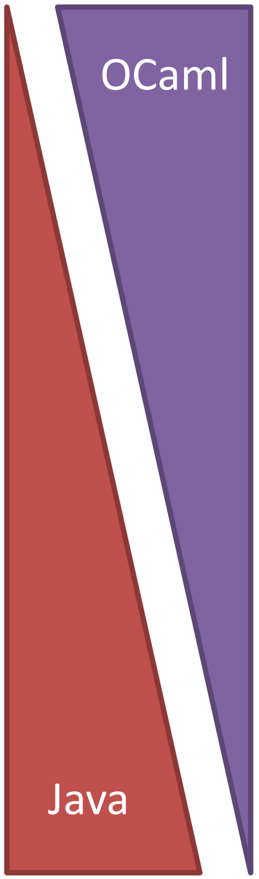
- Java Bootcamp!
  - Wednesday, 6-8 pm
  - https://zoom.us/j/806001667

- General advice for the next few lectures: Ask questions, but don't stress about the details until you need them.

- Java resources:
  - Our lecture notes
  - CIS 110 website and textbook
  - Online Java textbook (http://math.hws.edu/javanotes/) linked from "CIS 120 Resources" on course website
  - Penn Library: Electronic access to "Java in a Nutshell" (and all other O'Reilly books)
  - Piazza

CIS 120 Overview

- Declarative (Functional) programming
  - *persistent* data structures
  - *recursion* is main control structure
  - frequent use of functions as data
- Imperative programming
  - *mutable* data structures (that can be modified “in place”)
  - *iteration* is main control structure
- Object-oriented (and reactive) programming
  - mutable data structures / iteration
  - heavy use of functions (objects) as data
  - pervasive “abstraction by default”



Java and OCaml together

me

Guy Steele, one of the principal designers of Java

Xavier Leroy, one of the principal designers of OCaml

Moral: Java and OCaml are not so far apart…

Recap: The Functional Style

- Core ideas:
  - immutable (persistent / declarative) data structures
  - recursion (and iteration) over tree structured data
  - functions as data
  - generic types for flexibility (i.e. ‘a list)
  - abstract types to preserve invariants (i.e. BSTs)
  - *simple model of computation (substitution)*

- Good for:
  - elegant descriptions of complex algorithms and/or data
  - small-scale compositional design
  - “symbol processing” programs (compilers, theorem provers, etc.)
  - parallelism, concurrency, and distribution

Functional programming

OCaml

- Immutable lists primitive, tail recursion
- Datatypes and pattern matching for tree structured data
- First-class functions, transform and fold
- Generic types
- Abstract types through module signatures

Java

- No primitive data structures, no tail recursion
- Trees must be encoded by objects, mutable by default
- First-class functions less common*
- Generic types
- Abstract types through public/private modifiers

*completely unsupported until Java 8

OCaml vs. Java for FP

```
type 'a tree =
   | Empty
   | Node of ('a tree) * 'a * ('a tree)

let is_empty (t:'a tree) : bool =
  begin match t with
    | Empty -> true
    | _     -> false
  end

let t : int tree = Node(Empty,3,Empty)
let ans : bool = is_empty t
```

OCaml provides a succinct, clean notation for working with generic, immutable, tree-structured data. Java requires a lot more "boilerplate".

```
interface Tree<A> {
  public boolean isEmpty();
}
class Empty<A> implements Tree<A> {
  public boolean isEmpty() {
     return true;
  }
}
class Node<A> implements Tree<A> {
  private final A v;
  private final Tree<A> lt;
  private final Tree<A> rt;

  Node(Tree<A> lt, A v, Tree<A> rt) {
    this.lt = lt; this.rt = rt; this.v = v;
  }

  public boolean isEmpty() {
    return false;
  }
}

class Program {
  public static void main(String[] args) {
    Tree<Integer> t =
    new Node<Integer>(new Empty<Integer>(),
     3, new Empty<Integer>());
    boolean ans = t.isEmpty();
  }
}
```

Other Popular Functional Languages

F#: Most similar to OCaml,
Shares libraries with C#

Haskell (CIS 552)
Purity + laziness

Swift
iOS programming

Clojure
Dynamically typed
Runs on JVM

Racket: LISP descendant;
widely used in education

Scala
Java / OCaml hybrid

Recap: The imperative style

- Core ideas:
  - computation as change of state over time
  - distinction between primitive and reference values
  - aliasing
  - linked data-structures and iteration control structure
  - generic types for flexibility (i.e. ‘a queue)
  - abstract types to preserve invariants (i.e. queue invariant)
  - *Abstract Stack Machine model of computation*

- Good for:
  - numerical simulations
  - implicit coordination between components (queues, GUI)
  - explicit interaction with hardware

Imperative programming

OCaml

- No null. Partiality must be made explicit with **options**.
- Code is an **expression** that has a value. Sometimes computing that value has other effects.
- References are **immutable** by default, must be explicitly declared to be mutable

Java

- Most types have a **null** element. Partial functions can return **null**.
- Code is a sequence of **statements** that have effects, sometimes using expressions to compute values.
- References are **mutable** by default, must be explicitly declared to be constant

Explicit vs. Implicit Partiality

OCaml identifiers

- Cannot be changed once created; only mutable fields can change

```
type 'a ref = { mutable contents: 'a }
let x = { contents = counter () }
;; x.contents <- counter ()
```

- Cannot be null, must use options

```
let y = { contents = Some (counter ())}
;; y.contents <- None
```

- Accessing the value requires pattern matching

```
;; match y.contents with
    | None -> failwith "NPE"
    | Some c ->  c.inc ()
```

Java variables

- Can be assigned to after initialization

```
Counter x = new Counter ();
x = new Counter ();
```

- Can always be null

```
Counter y = new Counter ();
y = null;
```

- Check for null is implicit whenever a variable is used

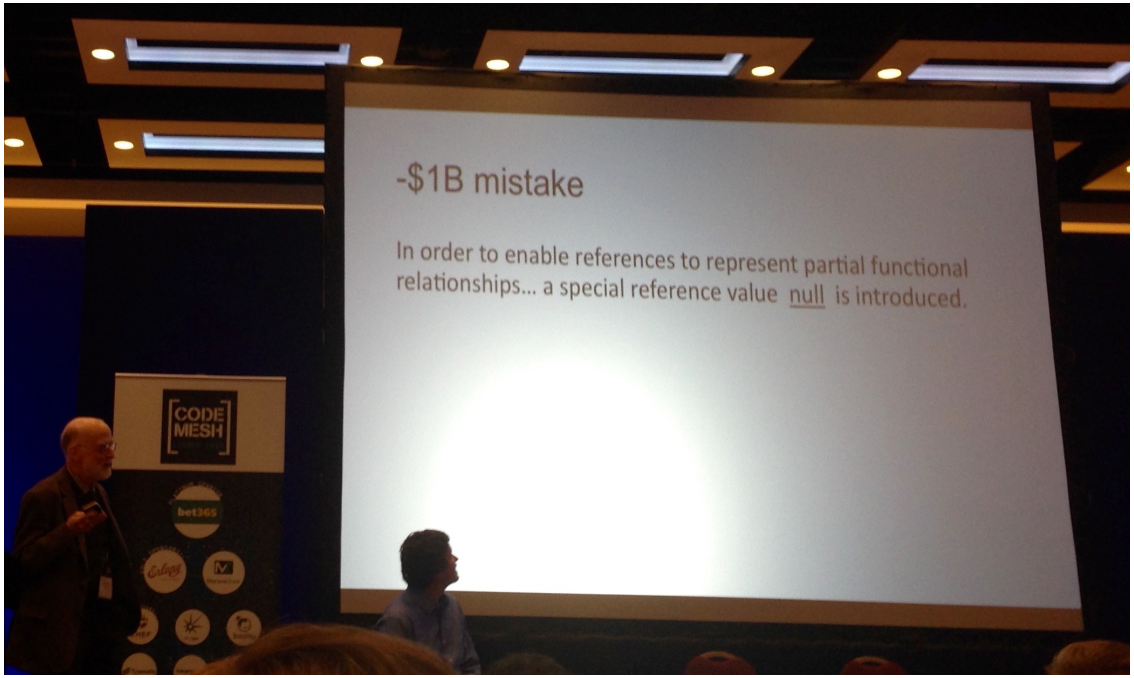
```
y.inc();
```

- If null is used as if it were an object (i.e. for a method call) then a **NullPointerException** occurs

The Billion Dollar Mistake

"I call it my billion-dollar mistake. It was the invention of the null reference in 1965. … This has led to innumerable errors, vulnerabilities, and system crashes, which have probably caused a billion dollars of pain and damage in the last forty years. "

Sir Tony Hoare, QCon, London 2009



Java Core Language

differences between OCaml and Java

Structure of a Program

OCaml

- All code lives in (perhaps implicitly named) **modules**.
- Modules may contain multiple **type definitions**, **let**-bound value **declarations**, and top-level **expressions** that are executed in the order they are encountered.

Java

- All code lives in explicitly named **classes**.
- Classes are types (of objects).
- Classes contain **field declarations** and **method definitions**.
- There is a single "entry point" of the program where it starts running, which must be a method called `main`.

Expressions vs. Statements

- OCaml is an *expression language*
  - Every program phrase is an expression (and returns a value)
  - The special value () of type `unit` is used as the result of expressions that are evaluated only for their side effects
  - Semicolon is an *operator* that combines two expressions (where the left-hand one returns type unit)

- Java is a *statement language*
  - Two-sorts of program phrases: expressions (which compute values) and statements (which don't)
  - Statements are *terminated* by semicolons
  - Any expression can be used as a statement (but not vice-versa)

Types

- As in OCaml, every Java *expression* has a type
- The type describes the value that an expression computes

Expression form	**Example**	**Type**
Variable reference	x	Declared type of variable
Object creation	new Counter ()	Class of the object
Method call	c.inc()	Return type of method
Equality test	x == y	boolean
Assignment	x = 5	*don't use as an expression!!*

Type System Organization

	OCaml	**Java**
primitive types (values stored "directly" in the stack)	int, float, char, bool, …	int, float, double, char, boolean, …
structured types (a.k.a. *reference types* — values stored in the heap)	tuples, datatypes, records, functions, arrays (*objects encoded as records of functions*)	objects, arrays (*records, tuples, datatypes, strings, first-class functions are special cases of objects*)
generics	'a list	List<A>
abstract types	module types (signatures)	interfaces public/private modifiers

Arithmetic & Logical Operators

<table>
<tr><th>OCaml</th><th>Java</th><th></th></tr>
<tr><td>=, ==</td><td>==</td><td>equality test</td></tr>
<tr><td><>, !=</td><td>!=</td><td>inequality</td></tr>
<tr><td>>, >=, <, <=</td><td>>, >=, <, <=</td><td>comparisons</td></tr>
<tr><td>+</td><td>+</td><td>addition</td></tr>
<tr><td>^</td><td>+</td><td>string concatenation</td></tr>
<tr><td></td><td></td><td>subtraction (and unary minus)</td></tr>
<tr><td>*</td><td>*</td><td>multiplication</td></tr>
<tr><td>/</td><td>/</td><td>division</td></tr>
<tr><td>mod</td><td>%</td><td>remainder (modulus)</td></tr>
<tr><td>not</td><td>!</td><td>logical “not”</td></tr>
<tr><td>&&</td><td>&&</td><td>logical “and” (short-circuiting)</td></tr>
<tr><td>||</td><td>||</td><td>logical “or” (short-circuiting)</td></tr>
</table>

Java: Operator Overloading

- The *meaning* of an operator in Java is determined by the *types* of the values it operates on:
  - Integer division

    `4/3` ⇒ **`1`**
  - Floating point division

    `4.0/3.0` ⇒ **`1.3333333333333333`**
  - Automatic conversion from int to float

    `4/3.0` ⇒ **`1.3333333333333333`**

- Overloading is a general mechanism in Java
  - we'll see more of it later

Equality

- like OCaml, Java has two ways of testing reference types for equality:
  - "pointer equality"

    o1 == o2
  - "deep equality"

    o1.equals(o2)

every object provides an "equals" method that should "do the right thing" depending on the class of the object

- Normally, you should use == to compare primitive types and ".equals" to compare objects

Strings

- `String` is a *built in* Java class
- Strings are sequences of (unicode) characters

  `""` `"Java"` `"3 Stooges"` `"富士山"`
- + means String concatenation (overloaded)

  `"3" + " " + "Stooges"` ⇒ `"3 Stooges"`
- Text in a String is immutable (like OCaml)
  - but variables that store strings are not
  - `String x = "OCaml";`
  - `String y = x;`
  - Immutability: can't do anything to `x` so that `y` changes
- The `.equals` method returns true when two strings contain the *same* sequence of characters

What is the value of ans at the end of this program?

```
String x = "CIS 120";
String z = "CIS 120";
boolean ans = x.equals(z);
```

1. true
2. false
3. NullPointerException

Answer: true

This is the preferred method of comparing strings!

What is the value of ans at the end of this program?

```
String x1 = "CIS ";
String x2 = "120";
String x = x1 + x2;
String z = "CIS 120";
boolean ans = (x == z);
```

1. true
2. false
3. NullPointerException

Answer: false

Even though x and z both contain the characters “CIS 120”, they are stored in two different locations in the heap.

What is the value of ans at the end of this program?

```
String x = "CIS 120";
String z = "CIS 120";
boolean ans = (x == z);
```

1. true
2. false
3. NullPointerException

Answer: true(!)
Why? Since strings are immutable, two identical strings that are known when the program is compiled can be aliased by the compiler (to save space).

Moral

Always use s1.equals(s2) to compare Strings!

Compare strings with respect to their content, not where they happen to be allocated in memory…

Object Oriented Programming

Recap: The OO Style

- Core ideas:
  - objects (state encapsulated with operations)
  - dynamic dispatch (“receiver” of method call determines behavior)
  - classes (“templates” for object creation)
  - subtyping (grouping object types by common functionality)
  - inheritance (creating new classes from existing ones)
- Good for:
  - GUIs!
    - complex software systems that include many different implementations of the same “interface” (set of operations) with different behaviors
  - Simulations
    - designs with an explicit correspondence between “objects” in the computer and things in the real world

"Objects" in OCaml

```
(* The type of counter objects *)
type counter = {
    inc  : unit -> int;
    dec  : unit -> int;
}

(* Create a counter "object" *)
let new_counter () : counter =
  let r = {contents = 0} in
  {
    inc = (fun () ->
      r.contents <- r.contents + 1;
      r.contents);
    dec = (fun () ->
      r.contents <- r.contents - 1;
      r.contents)
 }
```

Why is this an object?

- *Encapsulated local state* only visible to the methods of the object
- Object is *defined by what it can do*—local state does not appear in the interface
- There is a way to *construct* new object values that behave similarly

OO terminology

- *Object*: a structured collection of encapsulated *fields* (aka *instance variables*) and *methods*
- *Class*: a template for creating objects
- The class of an object specifies…
  - the types and initial values of its local state (fields)
  - the set of operations that can be performed on the object (methods)
  - one or more *constructors*: code that is executed when the object is created (optional)
- Every (Java) object is an *instance* of some class

OO programming

OCaml (part we've seen)

- Explicitly create objects using a record of higher order functions and hidden state

- Flexibility through ***composition***: objects can only implement one interface

```
type button =
    widget *
    label_controller *
     notifier_controller
```

Java (and C, C++, C#)

- Primitive notion of object creation (classes, with fields, methods and constructors)

- Flexibility through ***extension***: ***Subtyping*** allows related objects to share a common interface

```
class Button extends Widget {
  /* Button is a subtype
     of Widget */

}
```

Objects in Java

class declaration

```
public class Counter {

   private int r;

   public Counter () {
      r = 0;
   }

   public int inc () {
      r = r + 1;
      return r;
   }

   public int dec () {
      r = r - 1;
      return r;
   }
}
```

class name

instance variable

constructor

methods

object creation and use

```
public class Main {

 public static void
    main (String[] args) {

      Counter c = new Counter();

      System.out.println( c.inc() );

   }
}
```

constructor invocation

method call

Encapsulating local state

```
public class Counter {

  private int r;

  public Counter () {
    r = 0;
  }

  public int inc () {
    r = r + 1;
    return r;
  }

  public int dec () {
    r = r - 1;
    return r;
  }
}
```

r is *private*

constructor and methods can refer to r

```
public class Main {

  public static void
     main (String[] args) {

       Counter c = new Counter();

       System.out.println( c.inc() );

    }
}
```

other parts of the program can only access public members

method call

Encapsulating local state

- Visibility modifiers make the state local by controlling access
- Basically:
  - public : accessible from anywhere in the program
  - private : only accessible inside the class
- Design pattern — first cut:
  - Make *all* fields private
  - Make constructors and non-helper methods public

(Java offers a couple of other protection levels — "protected" and "package protected". The details are not important at this point.)