OOP vs. FP

- **Object-oriented programming (OOP)**
  - Computation as interactions between objects
  - Objects encapsulate state, which is usually mutable
    - Accessed / modified via object’s public methods

- **Functional programming (FP)**
  - Computation as evaluation of functions
    - Mutable data used to improve efficiency
  - Higher-order functions implemented as closures
    - Closure = function + environment

Relating Objects to Closures

- **An object**...
  - Is a collection of fields (data)
  - ...and methods (code)
  - When a method is invoked
    - Method has implicit this parameter that can be used to access fields of object

- **A closure**...
  - Is a pointer to an environment (data)
  - ...and a function body (code)
  - When a closure is invoked
    - Function has implicit environment that can be used to access variables

```plaintext
class C {
    int x = 0;
    void set_x(int y) { x = y; }
    int get_x() { return x; }
}
```

```plaintext
let make () =
    let x = ref 0 in
    ( (fun y -> x := y),
      (fun () -> !x) )
```

```plaintext
C c = new C();
c.set_x(3);
int y = c.get_x();
```

```plaintext
let make () =
    let x = ref 0 in
    ( (fun y -> x := y),
      (fun () -> !x) )
```

```plaintext
fun y -> x := y fun () -> !x
```

```plaintext
let (set, get) = make ();;
set 3;;
let y = get ();;
```
Encoding Objects with Closures

- We can apply this transformation in general

  ```
  class C { f1 ... fn; m1 ... mn; }
  ```

  becomes

  ```
  let make () =
  let f1 = ...
  ...
  and fn = ... in
  ( fun ... , (* body of m1 *)
  ...
  fun ... , (* body of mn *)
  )
  ```

  - `make ()` is like the constructor
  - The closure environment contains the fields

Relating Closures to Objects

```
let add1 x = x + 1
class Add1 implements IntIntFun {
  Integer eval(Integer x) {
    return x + 1;
  }
}
new Add1().eval(2);
new Add1().eval(3)
```

```interface IntIntFun {
  Integer eval(Integer x);
}
class Add1 implements IntIntFun {
  Integer eval(Integer x) {
    return x + 1;
  }
}
```
Relating Closures to Objects

```java
class Add implements Func<Int, Func<Int, Int>> {
    private static class AddClosure implements Func<Int, Int> {
        private final Int a;
        AddClosure(Int a) {
            this.a = a;
        }
        Integer eval(Int b) {
            return a + b;
        }
    }
    Func<Int, Int> eval(Int x) {
        return new AddClosure(x);
    }
}
```

```java
let add a b = a + b;
```

Encoding Closures with Objects

- We can apply this transformation in general
  ```java
  let h f ... = ...f y...
  ```
- becomes
  ```java
  interface F<T,U> { U eval(T x); }
  class G implements F<T,U> {
      U eval(T x) { /* body of fn */ }
  }
  class C {
      Typ1 h(F<Typ2,Typ3> f, ...) {
          ...f.eval(y)...
      }
  }
  ```

- $F$ is the interface to the callback
- $G$ represents the particular function

Code as Data

- Closures and objects are related
  - Both of them allow
    - Data to be associated with higher-order code
    - Pass code around the program
  - The key insight in all of these examples
    - Treat code as if it were data
      - Allowing code to be passed around the program
      - And invoked where it is needed (as callback)
  - Approach depends on programming language
    - Higher-order functions (OCaml, Ruby, Lisp)
    - Function pointers (C, C++)
    - Objects with known methods (Java)

Code as Data (cont.)

- This is a powerful programming technique
  - Solves a number of problems quite elegantly
    - Create new control structures (e.g., Ruby iterators)
    - Add operations to data structures (e.g., visitor pattern)
    - Event-driven programming (e.g., observer pattern)
  - Keeps code separate
    - Clean division between higher & lower-level code
  - Promotes code reuse
    - Lower-level code supports different callbacks
An Integer List Abstraction in Java

```java
public class MyList {
    private class ConsNode {
        int head; MyList tail;
        ConsNode (int h, MyList l) { head = h; tail = l; }
    }
    private ConsNode contents;
    public MyList () {
        contents = null;
    }
    public MyList (int h, MyList l) {
        contents = new ConsNode (h, l);
    }
    public MyList cons (int h) {
        return (new MyList (h, this));
    }
    public int hd () {
        return contents.head;
    }
    public MyList tl () {
        return contents.tail;
    }
    public boolean isNull () {
        return (contents == null);
    }
}
```

Recall a Useful Higher-Order Function

```plaintext
let rec map f = function
    [] -> []
  | (h::t) -> (f h)::(map f t)
```

- Map applies an arbitrary function f
  - To each element of a list
  - And returns the resulting modified list
- Can we encode this in Java?
  - Using object oriented programming

A Map Method for Lists in Java

- Problem – Write a map method in Java
  - Must pass a function into another function
- Solution
  - Can be done using an object with a known method
  - Use interface to specify what method must be present

```java
public interface IntFunction {
    int eval(int arg);
}
```

A Map Method for Lists (cont.)

- Examples
  - Two classes which both implement Function interface

```java
class AddOne implements IntFunction {
    int eval (int arg) {
        return (arg + 1);
    }
}
class MultTwo implements IntFunction {
    int eval(int arg) {
        return (arg * 2);
    }
}
The New List Class

```java
class MyList {
    // ...
    public MyList map (IntFunction f) {
        if (this.isNull()) return this;
        else return (this.tl()).map(f).cons (f.eval (this.hd()));
    }
}
```

Applying Map To Lists

Then to apply the function, we just do

```java
MyList l = ...;
MyList l1 = l.map(new AddOne());
MyList l2 = l.map(new MultTwo());
```

We Can Do This for Fold Also!

Recall fold

```
let rec fold f a = function
  | [] -> a
  | (h::t) -> fold f (f a h) t
```

- Fold accumulates a value (in a) as it traverses a list
- f is used to determine how to “fold” the head of a list into a

This can be done in Java using an approach similar to map!

A Fold Method for Lists in Java

Problem – Write a fold method in Java

- Must pass a function into another function

Solution

- Can be done using an object with a known method
- Use interface to specify what method must be present

```java
public interface IntBinFunction {
    Integer eval(Integer arg1, Integer arg2);
}
```
A Fold Method for Lists (cont.)

- Examples
  - A classes which implements IntBinFunction interface

```java
class Sum implements IntBinFunction {
    Integer eval(Integer arg1, Integer arg2) {
        return new Integer(arg1 + arg2);
    }
}
```

- Note: this is not curried
  - How might you make it so?

The New List Class

```java
class MyList {
    ... public MyList map (IntFunction f) {
        if (this.isNull()) return this;
        else return (this.tl()).map(f).cons (f.eval (this.hd()));
    }
    public int fold (IntBinFunction f, int a) {
        if (this.isNull()) return a;
        else return (this.tl()).fold(f, f.eval(a, this.hd()));
    }
}
```

Applying Fold to Lists

- To apply the fold function, we just do this:

```java
MyList l = ...;
int s = l.fold (new Sum(), 0);
```

- The result is that s contains the sum of the elements in l

Java 8 eases the syntax

- Java 8 allows you to make objects that act as functions, more easily
  - Instead of this
    ```java
    MyList l = ...;
    MyList l1 = l.map(new AddOne());
    MyList l2 = l.map(new MultTwo());
    ```
  - Write this
    ```java
    MyList l = ...;
    MyList l1 = l.map((x) -> x + 1);
    MyList l2 = l.map((y) -> y * 2);
    ```