Functional Programming (2/2) and Intro to Cool

Martin Kellogg

Today's Agenda

- Finish introduction to functional programming
  - **polymorphism**
  - higher-order functions
    - fold
    - sorting
- Introduction to Cool
  - syntax
  - objects
  - methods
  - types

Polymorphism

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Recall that α means "any one type"

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length [1;2;3] = 3
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val length : α list -> int

length [1;2;3] = 3
length [“algol”; ”smalltalk”; ”ml”] = 3
```

Recall that α means "any one type"

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length ["algol"; "smalltalk"; "ml"] = 3
length [1 ; "algol" ] = ?
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Recall that α means
“any one type”

```
File "list-example.ml", line 1, characters 25-26:
1 | let myList = [ "algol" ; 1 ] in
                             ^
Error: This expression has type int but an expression was expected of type
         string
```

```
length [1 ; “algol” ] = ?
```

Higher-order functions

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f is itself a function!

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val map : (α -> β) -> ?
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val map : (α -> β) -> α list -> β list
let offset = 10 in
let myfun x = x + offset in
val myfun : ?
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val myfun : int -> int
map myfun [1;8;22] = ?
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Extremely powerful programming technique:

- general iterators
- implement abstraction

The Story of Fold

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- We can also imagine:

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  - **sum** [1; 5; 8] = 14
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  - **and** [true; true; false] = false

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  - **reverse** [1; 5; 8] = [8; 5; 1]

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- We can also imagine:

sum	[1; 5; 8]	= 14
product	[1; 5; 8]	= 40
and	[true; true; false]	= false
or	[true; true; false]	= true
filter	(fun x -> x > 4) [1; 5; 8]	= [5; 8]
reverse	[1; 5; 8]	= [8; 5; 1]
mem	5 [1; 5; 8]	= true

The Story of Fold

How can we **build** all of these?

- We've seen **length** and **map**
- We can also imagine:
    - **sum** [1; 5; 8] = 14
    - **product** [1; 5; 8] = 40
    - **and** [true; true; false] = false
    - **or** [true; true; false] = true
    - **filter** (fun x -> x > 4) [1; 5; 8] = [5; 8]
    - **reverse** [1; 5; 8] = [8; 5; 1]
    - **mem** 5 [1; 5; 8] = true

The Story of Fold

- The *fold* operator comes from recursion theory (Kleene, 1952):

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let rec fold f acc lst = match lst with
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val fold : ?
```

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val fold : (α -> β -> α) -> α -> β list -> α
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Note: acc type and return type are the same!

```
val fold : (α -> β -> α) -> α -> β list -> α
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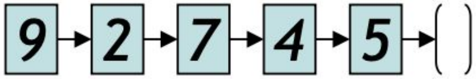
```

- on the whiteboard, this example (f is +):



Let’s build things out of fold

- **length** lst = fold (fun acc elt -> ???) ? lst

Let’s build things out of fold

- **length** lst = fold (fun acc elt -> acc + 1) 0 lst

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Let’s build things out of fold

- **length** lst = fold (fun acc elt -> acc + 1) 0 lst
- **sum** lst = fold (fun acc elt -> acc + elt) 0 lst
- **product** lst = fold (fun acc elt -> acc * elt) 1 lst

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Let’s build things out of fold

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- sum lst = fold (fun acc elt -> acc + elt) 0 lst
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- and lst = fold (fun acc elt -> acc & elt) true lst

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- think you can do **or** on your own?

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- think you can do **or** on your own?
  - what about **reverse**?

Let’s build things out of fold, part 2

- **reverse** lst = fold (fun acc elt -> ???) ? lst

Let’s build things out of fold, part 2

- **reverse** lst = <u>fold</u> (fun acc elt -> acc @ [e]) [] lst

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  - note types: **(acc : α list) (e : α)**

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- **reverse** lst = fold (fun acc elt -> acc @ [e]) [] lst
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- **filter** keep_it lst = fold (fun acc elt -> ???) ? lst

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  - note types: (acc : bool) (e : α)

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- Could we do **map**?
  - Recall: map (fun x -> x +10) [1;2] = [11;12]

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- Could we do **map**?
  - Recall: map (fun x -> x +10) [1;2] = [11;12]
  - Let's do it together…

Let's build things out of fold, part 3 (map)

```
let map myfun lst =
        fold (fun acc elt ->          ???          ) ? lst
```

Let’s build things out of fold, part 3 (map)

```
let map myfun lst =
          fold (fun acc elt -> (myfun elt) :: acc) [] lst
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- Types of:
  - myfun : **α -> β**
  - lst : **α list**
  - acc : **β list**
  - elt : **α**

Let’s build things out of fold, part 3 (map)

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let map myfun lst =
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```

- Types of:
  - myfun : **α -> β**
  - lst : **α list**
  - acc : **β list**
  - elt : **α**
- Could we do **sort**?

Sorting examples

let **langs = ["fortran"; "algol"; "c"]** in

- sort (fun a b -> ???) langs = **["algol"; "c"; "fortran"]**

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Sorting examples

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- sort (fun a b -> a < b) langs = [“algol”; “c”; “fortran”]
- sort (fun a b -> a > b) langs = [“fortran”; “c”; “algol”]
- sort (fun a b -> strlen a < strlen b) langs = [“c”; “algol”; “fortran”]

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- sort (fun a b -> strlen a < strlen b) langs = [“c”; “algol”; “fortran”]

- Recall Java’s **Comparator** interface
  - in this functional style, our implementations are much simpler!

Partial Application and Currying

```
let myadd x y = x + y
val myadd : int -> int -> int
myadd 3 5 = 8
```

Partial Application and Currying

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let myadd x y = x + y
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- How do we know what this means? We use ***referential transparency***! Basically, just substitute it in.

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```
val addtwo : int -> int
addtwo 77 = 79
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Partial Application and Currying

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```

- How do we know what this means? We use ***referential transparency***! Basically, just substitute it in.

```
val addtwo : int -> int
addtwo 77 = 79
```

- called ***Currying***: “if you fix some arguments, you get a function of the remaining arguments” (remember Monday’s trivia question?)

Trivia Break: Current Events

This Chinese artificial intelligence company released a chatbot using its latest R1 model on January 10th. By January 27th, it had surpassed ChatGPT as the most-downloaded free app on the iOS App Store in the United States. The R1 model is claimed to have been trained at small fraction of the cost of training other state-of-the-art foundation models, like GPT-4.

Trivia Break: History

The New York Times mentioned this thing in 279 articles between October 6, 1957, and October 31, 1957 (more than 11 articles per day). Its launch created a crisis reaction in the United States that kicked of the "Space Race" that culminated in the Apollo moon landings in the 1960s and 1970s. After its first orbit, the Telegraph Agency of the Soviet Union (TASS) transmitted: "As result of great, intense work of scientific institutes and design bureaus the first artificial Earth satellite has been built."

Today’s Agenda

- Finish introduction to functional programming
  - polymorphism
  - higher-order functions
    - fold
    - sorting
- **Introduction to Cool**
  - syntax
  - objects
  - methods
  - types

Cool Overview

- Recall Cool = “Classroom Object-Oriented Language”
  - Designed to be implementable in one semester

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- Give a taste of implementing modern features, such as:
  - Abstraction
  - Static Typing
  - Inheritance
  - Dynamic Dispatch
  - And more ...

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  - Designed to be implementable in one semester
- Give a taste of implementing modern features, such as:
  - Abstraction
  - Static Typing
  - Inheritance
  - Dynamic Dispatch
  - And more ...
- But many “grungy” things are left out

A Simple Cool Example

```
class Point {
    x : Int <- 1;
    y : Int; (* use default value *)
};
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  - A special `Main` class with a special method `main()`
  - Classes are like those in Java or Python or C++

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- Cool programs are sets of class definitions
  - A special `Main` class with a special method `main()`
  - Classes are like those in Java or Python or C++
- ***class*** = a collection of fields and methods

A Simple Cool Example

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    x : Int <- 1;
    y : Int; (* use default value *)
};
```

- Cool programs are sets of class definitions
  - A special `Main` class with a special method `main()`
  - Classes are like those in Java or Python or C++
- ***class*** = a collection of fields and methods
- Instances of a class are ***objects***

Cool Objects

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class Point {
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- An object can be thought of as a **record** with a slot for each *attribute* (= field)

x	y
1	0

Cool Methods

A class can also define **methods** for manipulating its attributes

```
class Point {
    x : Int <- 1;
    y : Int; (* use default value *)
   movePoint(newx : Int, newy : Int) : Point {
            { x <- newx;
              y <- newy;
              self;
            } -- close block expression
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Methods can refer to the current object using the self keyword

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Aside: yes, the placement of semicolons is arbitrary. Still, don't get it wrong.

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  - conveniently, this means there is **no dereference syntax**
    - e.g., you can't write `f.x` in Cool!
  - instead, all attributes are accessed directly by name
    - simplifies reasoning about **scopes** (we'll come back to it)

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Another topic we'll cover in a lot more detail later!

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class ColorPoint extends Point {
     color : Int <- 0;
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Can add new attributes

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Can redefine methods (= Java's *overriding*)

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Can still reference attributes defined in superclass

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  - compiler **infers types** for expressions (like Java or C)

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- Another way of phrasing this: … is well-typed iff ColorPoint is a ***subtype*** of Point
- Cool’s ***type safety theorem*** says that a well-typed program **cannot** result in run-time type errors

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Aside that will come up again: *static* means “just by reading the program text”; *dynamic* means “at run time”

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  - Arithmetic, logic operators, comparison operators, etc.
- Missing: arrays, floats, interfaces, exceptions…
  - any other missing things you noticed?

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  - we'll cover garbage collectors in more detail (much) later in the semester

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- PA2c1 is due **next Friday** (do it next week!)
  - this is a testing assignment: you’ll just write Cool programs

Bonus for those reading the slides :)

- Questions about **fold** are very popular on tests! If I say “write me a function that does foozle to a list”, you should be able to code it up with fold in OCaml-ish syntax.