CSCI 334: Principles of Programming Languages

Lecture 6: ML II

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Williams

Announcements

HW3 is now out.

I will assume that you want to stay with your current partner. If this is not true, email me by tomorrow night and I will pair you with another student.

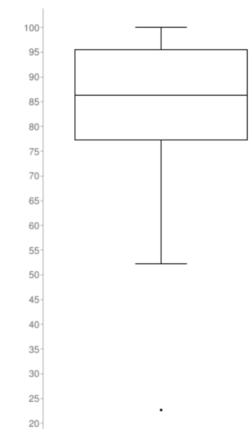
Announcements

midterm: before or after spring break?

“before” wins (by a lot)

Announcements

HW0



Announcements

HW1 solutions handout

(fix: S2 is not worth 40 points!)

Announcements

Reminder: Thursday help (poorly attended)

Static vs. dynamic environments

```
fun add_one x = x + 1
```

What do we know about `x`?

What about `1`?

What about `add_one`?

Static vs. dynamic environments

```
fun add_one x = x + 1
```


What do we know about `x`? `int`

What about `1`? `int`; also `1`

What about `add_one`? `int -> int`

Static vs. dynamic environments

```
fun add_one x = x + 1
```

Static environment:

Facts about a program that are always true.

E.g., data types.

Other static facts:

- “always halts”
- fn is named “add_one”

Static vs. dynamic environments

```
fun add_one x = x + 1
add_one 3
```

What do we know about `x`?

What about `add_one 3`?

Static vs. dynamic environments

```
fun add_one x = x + 1
add_one 3
```

What do we know about `x`? `x = 3`

What about `add_one 3`? `add_one 3 = 4`

Static vs. dynamic environments

```
fun add_one x = x + 1
```

Dynamic environment:

Facts about a program that are true for a given invocation of the program.

E.g., values.

Other dynamic facts:

- “halts for given value”

Types

Data type: a set of values and permissible operations on those values.

`…, ~1.11, ~1.1, ~1.0, 0, 1.0, 1.1, 1.11, … ∈ real`

`+, -, <, >, <=, >=`

Notice that = is not permitted

```
- 1.0 = 1.0;
stdIn:91.1-91.10 Error: operator and operand don't agree [equality type required]
  operator domain: ''Z * ''Z
  operand:         real * real
  in expression:
    1.0 = 1.0
```

Types

We usually can determine types statically.

Some languages where we do:

Java, Standard ML, Go, Rust, …

Some languages where we don't:

Python, Ruby, Lisp, R, …

Types

ML's uses a "structural type system"

Java uses a "nominal type system".

Nominal Types

Types are equivalent if they use the same *name* or if there is an explicit *subtype relationship* between names.

Matching names

```
int n = 3;
int m = 4;
n == m;
false
```

Subtype relationship

```
class Animal …
class Cat extends Animal …
Animal a = new Animal();
Cat c = new Cat();
c.equals(a) == true (maybe)
```

Structural Types

Types are equivalent if they have the same features. Base case in ML: same name; inductive case: same composition of names.

Matching names	Structural relationship
`val n = 3`	`val a = (1,(2,"hi"))`
`val m = 4`	`val b = (1,(2,"hi"))`
`n = m`	`a = b`
`false`	`true`

map

This is essentially the same idea as in Lisp, but it is type-safe.

```
val xs = [1,2,3,4]
map (fn x => x + 1) xs
```

OK

```
val xs = ["a","b","c"]
map (fn x => x + 1) xs
```

Not OK

fold

Like map, in that it operates over lists, but only returns a single, "accumulated" object.

```
fun sum (l:int list):int =
  case l of
    [] => 0
  | x::xs => x + (sum xs)

fun concat (l:string list):string =
  case l of
    [] => ""
  | x::xs => x ^ (concat xs)
```

These look similar, no? Differences?

fold

Like map, in that it operates over lists, but only returns a single, "accumulated" object.

```
fun sum (l:int list):int =
  case l of
    [] => 0
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fun concat (l:string list):string =
  case l of
    [] => ""
  | x::xs => x ^ (concat xs)
```

These look similar, no? Differences?

fold

Rewrite to add an accumulator variable

```
fun sum' (acc:int) (l:int list):int =
  case l of
    [] => acc
  | x::xs => sum' (acc+x) xs

sum’ 0 [1,2,3,4]

fun concat' (acc:string) (l:string list):string =
  case l of
    [] => acc
  | x::xs => concat' (acc^x) xs

concat’ “” [“hello”, “world”]
```

fold

Rewrite to add an accumulator variable

```
fun sum' (acc:int) (l:int list):int =
  case l of
    [] => acc
  | x::xs => sum' (acc+x) xs

sum’ 0 [1,2,3,4]

fun concat' (acc:string) (l:string list):string =
  case l of
    [] => acc
  | x::xs => concat' (acc^x) xs

concat’ “” [“hello”, “world”]
```

fold

Rewrite to abstract over operation and type.

```
fun sum' (acc:int) (l:int list):int =
  case l of
    [] => acc
  | x::xs => sum' (acc+x) xs
```

What is the function here?

```
fun f x y = x + y

val f = fn : int -> int -> int
```

fold

Rewrite to abstract over operation and type.

```
fun concat' (acc:string) (l:string list):string =
  case l of
    [] => acc
  | x::xs => concat' (acc^x) xs
```

What is the function here?

```
fun f x y = x ^ y

val f = fn : string -> string -> string
```

fold

What is the type of the function that "abstracts over" the first and second `f`'s?

```
fun f x y = x + y

val f = fn : int -> int -> int

fun f x y = x ^ y

val f = fn : string -> string -> string

val f = fn : 'a -> 'a -> 'a
```

fold

We now write a generic accumulation function.

```
fun sum' (acc:int) (l:int list):int =
  case l of
    [] => acc
  | x::xs => sum' (acc+x) xs

fun concat' (acc:string) (l:string list):string =
  case l of
    [] => acc
  | x::xs => concat' (acc^x) xs

fun foldl (f: 'a*'b->'b) (acc: 'b) (l: 'a list): 'b =
  case l of
    [] => acc
  | x::xs => foldl f (f(x,acc)) xs
```

fold (left)

`sum` and `concat` using `foldl`:

```
fun foldl (f: 'a*'b->'b) (acc: 'b) (l: 'a list): 'b =
  case l of
    [] => acc
  | x::xs => foldl f (f(x,acc)) xs

fun sum (l:int list):int =
 foldl (fn (x,acc) => acc+x) 0 l

fun concat (l:string list):string =
 foldl (fn (x,acc) => acc^x) "" l
```

fold (right)

```
fun foldr (f:'a*'b->'b) (accum:'b) (l:'a list):'b =
  case l of
    [] => acc
  | x::xs => f(x, (foldr f acc xs))
```

compare with

```
fun foldl (f: 'a*'b->'b) (acc: 'b) (l: 'a list): 'b =
  case l of
    [] => acc
  | x::xs => foldl f (f(x,acc)) xs
```

Activities