Introduction to ML

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Cornell CS 3110 Data Structures and Functional Programming

The ML Programming Language

- General purpose programming language designed by Robin Milner in 1970
  - Meta Language for verification
- Impure Functional Programming Language
  - Eager call by value evaluation
- Static strongly typed (like Java unlike C)
  - Protect its abstraction via type checking and runtime checking
- Polymorphic Type Inference
- Dialects: OCaml, Standard ML, F#

C is not Type Safe

```
int j;
union { int  i, int * p  } x;
x.i = 17 ;
j = *(x.p);
```

```
int i, *p;
i =17
p = (int *)  i;
```

Factorial in ML

```
let rec fac n = if n = 0 then 1 else n * fac (n - 1)

// val fac : int -> int = <fun>

let rec fac  n : int = if n = 0 then 1 else n * fac (n - 1)

let rec fac = function
  | 0 -> 1
  | n -> n * fac(n - 1)

let fac n =
   let rec ifac n acc =
      if n=0 then acc else ifac n-1, n * acc
  in ifac n, 1
```

Why Study ML?

- Functional programming will make you think differently about programming
  - Mainstream languages are all about state
  - Functional programming is all about values
- ML is “cutting edge”
  - Polymorphic Type inference
  - References
  - Module system
- Practical (small) Programming Language
- New ideas can help make you a better programmer, in any language

Plan

- Basic Programming in ML
- Type Inference for ML
- ML Modules & References

Simple Types

- Booleans

```
true -: bool = true
false -: bool = false
if …  then … else …types must match
```

- Integers

```
0, 1, 2,… -: int =0, 1, …
+, * ,    -: int * int  -> int
```

- Strings

  "I am a string" -: string ="I am a string"

- Floats

```
1.0, 2., 3.14159, … :- float = 1, 2, 3.14159
```

Scope Rules

- ML enforces static nesting on identifiers
  - To be explained lets
- let x = e1 in e2 $\equiv$ (λx.e2) e1

Tuples

```
4, 5, "abc" :- (int*int*string)=(4, 5, "abc")
```

```
let max1 (r1, r2) : float =
  if r1 < r2 then r2 else r1
val max1: float * float -> float = fun
```

```
let args = (3.5, 4.5)
val args: float * float = (3.5, 4.5)
```

```
max1 args
:-   float = 4.5
```

let $y(x_1: t_1, x_2: t2, \ldots, x_n : t_n) = e$

Pattern-Matching Tuples

let x_1: t_1, x_2: t_2, …, x_n :t_n = e

```
let max1 (pair : float * float) : float =
  let (r1, r2) = pair in
    if r1 < r2 then r2 else r1
val max1: float * float -> float = fun
```

```
let minmax (a, b) : float * float =
  if a < b then (a, b) else (b, a)
val minmax: float * float -> float *float= fun
```

```
let (mn, mx) = minmax (2.0, 1.0)
val mn float 1
val mx float 2
```

The compiler guarantees the absence of runtime errors

User-Defined Types

```
type day = Sun | Mon | Tue | Wed | Thu | Fri | Sat
```

```
let int_to_day (i : int) : day =
  match i mod 7 with
    0 -> Sun
  | 1 -> Mon
  | 2 -> Tue
  | 3 -> Wed
  | 4 -> Thu
  | 5 -> Fri
  | _ -> Sat
```

Records

```
type person = {first:string; last:string; age:int}
```

```
{first="John"; last="Amstrong"; age=77}
:- person ={first="John; last="Amstrong"; age=77}
```

```
{first="John"; last="Amstrong"; age=77}.age
 :- int = 77
```

```
let ja = {first="John"; last="Amstrong"; age=77}
 val ja : person = {first="John"; last="Amstrong"; age=77}
```

```
let = {first=first; last=last}  = ja
 val first:string="John"
 val last:string ="Amstrong"
```

Variant Records

- Provides a way to declare Algebraic data types

```
type expression = Number of  int | Plus of expression * expression
```

```
let rec eval_exp (e : expression) : int =
  match e with
    Number(n) -> n
   | Plus (left, right) -> eval_exp(left) + eval_exp(right)
val eval_exp : expression -> int = <fun>
```

```
 eval_exp (Plus(Plus(Number(2), Number(3)), Number(5)))
:- int = 10
```

Variant Records in C

```
struct exp {
    int tag ; /* Select between cases */
    union {
        struct  number { int : number; }
        struct  plus { struct exp *left, *right; }
            }
   }
```

Scope

- Local nested scopes
- Let constructs introduce a scope

```
let f x = e1 in e2
```

```
let x = 2
and y = 3
in   x + y
```

```
let rec even x = x = 0 || odd (x-1)
    and odd x = not (x = 0 || not (even (x-1)))
in
  odd 3110
```

Polymorphism

- A Polymorphic expression may have many types
- There is a “most general type”
- The compiler infers types automatically
- Programmers can restrict the types
- Pros:
  - Code reuse
  - Guarantee consistency
- Cons:
  - Compile-time
  - Some limits on programming

```
let max1 (r1, r2)  =
  if r1 < r2 then r2 else r1
val max1: ‘a * ‘a -> ‘a = fun
```

```
max1 (5, 7)
: - int = 7
```

```
max1 (5, 7.5)
```

Polymorphic Lists

```
[ ]
 - : 'a list = []
```

```
[2; 7; 8 ]
 - : int list = [2; 7; 8]
```

```
2 :: (7 ::  (8 ::[ ]))
 - : int list = [2; 7; 8]
```

```
[(2, 7) ; (4, 9) ; 5]
                    Error: This expression has type int but an expression
was expected of type
       int * int
```

Functions on Lists

```
let rec length l =
    match l with
   [] -> 0
  | hd :: tl  -> 1 + length tl
val length : 'a list -> int = <fun>
```

```
length [1; 2; 3] + length [“red”; “yellow”; “green”]
:- int = 6
```

```
length [“red”; “yellow”; 3]
```

Higher Order Functions

- Functions are first class objects
  - Passed as parameters
  - Returned as results
- Practical examples
  - Google map/reduce

Map Function on Lists

- Apply function to every element of list

```
let rec map f arg = function
     [] -> []
   | hd :: tl -> f hd :: (map f tl)

val map : ('a -> 'b) -> 'a list -> 'b list = <fun>
```

```
map (fun x -> x+1) [1;2;3]          [2,3,4]
```

- Compare to Lisp

```
(define map
    (lambda (f  xs)
      (if   (eq? xs ())   ()
         (cons (f  (car xs))  (map f  (cdr xs)))
   )))
```

More Functions on Lists

- Append lists

```
let rec append l1 l2 =
 match l1 with
  | []   -> l2
  | hd :: tl -> hd :: append (tl l2)
```

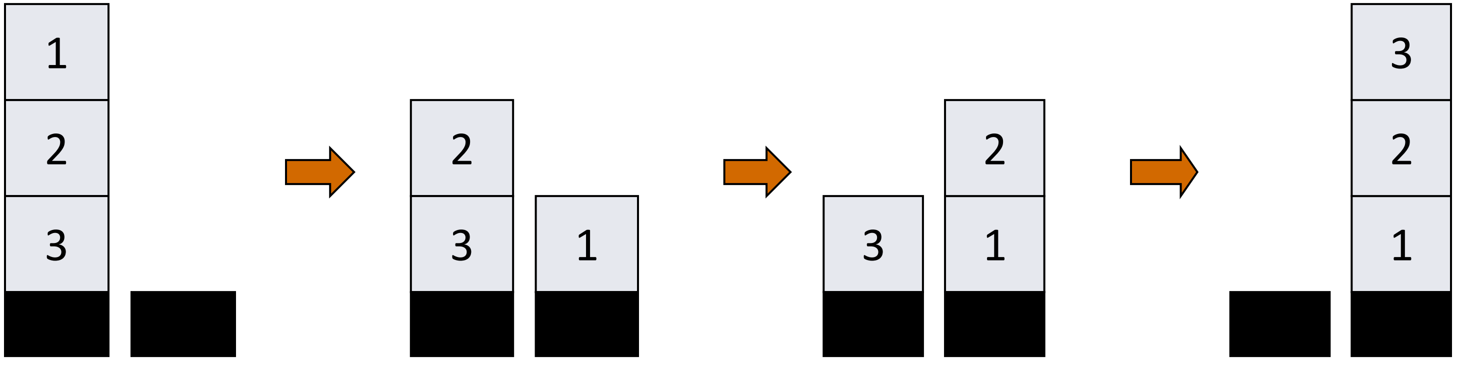
- Reverse a list

```
let rec reverse l = function
   | [] -> []
   | hd :: tl -> append (reverse tl)    [hd]
```

- Questions
  - How efficient is reverse?
  - Can it be done with only one pass through list?

More Efficient Reverse

```
let rev list =
    let rec aux acc = function
      | [] -> acc
      | h::t -> aux (h::acc) t in
    aux [] list
val rev : 'a list -> 'a list = <fun>
```



Currying

```
let plus (x, y) = x + y
val plus : int * int -> int = fun
```

```
let plus (z : int * int) = match z with (x, y) -> x + y
```

```
let plus = fun (z : int * int) -> match z with (x, y) -> x + y
```

```
let plus x y = x + y
val plus : int -> int -> int
```

```
let  p1 = plus 5
val p1 :  int -> int = fun
```

```
let  p2 = p1 7
val p2 :   int = 12
```

Functional Programming Languages

PL	types	evaluation	Side-effect
scheme	Weakly typed	Eager	yes
ML OCAML F#	Polymorphic strongly typed	Eager	References
Haskell	Polymorphic strongly typed	Lazy	None

Things to Notice

- Pure functions are easy to test

```
prop_RevRev l = reverse(reverse l) == l
```

- In an imperative or OO language, you have to
  - set up the state of the object and the external state it reads or writes
  - make the call
  - inspect the state of the object and the external state
  - perhaps copy part of the object or global state, so that you can use it in the post condition

Things to Notice

Types are everywhere.

```
reverse:: [w] -> [w]
```

- Usual static-typing panegyric omitted...
- In ML, types express high-level design, in the same way that UML diagrams do, with the advantage that the type signatures are machine-checked
- Types are (almost always) optional: type inference fills them in if you leave them out

Recommended ML Textbooks

- L. C. PAULSON: ML for the Working Programmer
- J. Ullman: Elements of ML Programming
- R. Harper: Programming in Standard ML

Recommended Ocaml Textbooks

- Xavier Leroy: The OCaml system release 4.02
  - Part I: Introduction
- Jason Hickey: Introduction to Objective Caml
- Yaron Minsky, Anil Madhavapeddy, Jason Hickey: Real World Ocaml

Summary

- Functional programs provide concise coding
- Compiled code compares with C code
- Successfully used in some commercial applications
  - F#, ERLANG, Jane Street
- Ideas used in imperative programs
- Good conceptual tool
- Less popular than imperative programs