Introduction to ML

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The ML Programming Language

- General purpose programming language designed by Robin Milner in 1970
  - Meta Language for verification
- Can be viewed as typed λ calculus with type inference
- 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>
```

```
int fac(int n) {
    if (n == 0) return 1 ; else return n * fac (n - 1) ;
 }
```

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
- Embedded in Java 8, Scala/Kotlin
- New ideas can help make you a better programmer, in any language

Plan

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

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 later
- let x = e1 in e2 $\equiv$ (λx.e2) e1
- let x: T = e1 in e2 $\equiv$ (λx:T.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
```

Pattern-Matching Tuples

```
let y(x1: t1, x2: t2, …, xn : tn )= e
```

$let\ y(x_1: t_1, x_2: t_2, \ldots, x_n : t_n) = e$

```
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
```

User-Defined Types C

```
enum day { Sun, Mon, Tue, Wed, Thu, Fri, Sat };
```

```
day int_to_day (int i)  {
     switch i % 7 {
    case 0: return Sun ;
    case 1: return Mon ;
    case 2: return Tue ;
    case 3: return Wed ;
    case 4: return Thu ;
    case 5: return Fri ;
    default: return 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"
```

C structs

```
struct person {char * first; char * last; int age} ;
```

```
struct person ja ={“John”, ”Amstrong”,77} ;
```

```
printf(“%d”, ja.age);
```

```
fn = ja.first; ln = ja.last ; ag = ja.age
```

```
ja.age = 78;
```

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

```
let rec eval_exp  = function
     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 {
    enum {Number, Binop} etype ; /* Select between cases */
    union {
        struct  number { int : num; }
        struct  plus { struct exp *left, *right; }
            }
   }
```

```
int eval_exp (struct exp e)  {
  switch e.etype {
    case Number: return e.number.num ;
    case Binop :  return eval_exp(e.plus.left) + eval_exp(e.plus.right);
   }
}
```

Wrong Variant Records in C

```
struct exp {
   enum {Number, Binop} etype ; /* Select between cases */
   union {
      struct  number { int : num; }
      struct  plus { struct exp *left, *right; }
         }
  }
```

```
int eval_exp (struct exp e)  {
  switch expression.etype {
    case Binop: return e.number.num ;
    case Number :  return eval_exp(e.plus.left) + eval_exp(e.plus.right);
   }
}
```

Define an Algebraic Type for Naturals

Int List Algebraic Type

Binary Search Tree

```
type tree = Leaf of  int | Node of tree * tree * int
```

```
let rec search t  key =
  match t with
    Leaf(n) -> key = n
  | Node (left, right, n) -> if key = n
                              then true
                              else if  key < n
                                   then search left key
                                        else search right key
```

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

- Functions can have many types
  - λx. x
  - λf. λg. λx. f (g x)

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:
  - Compilation-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 =
    match arg with

     [] -> []
    | 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)
val append 'a list -> 'a list -> 'a list
```

```
let rec append l1 l2 =
 match l1 with
 | []  -> []
 | hd :: tl -> hd :: append (tl l2)
val append 'a list -> `b -> 'a list
```

More Functions on Lists

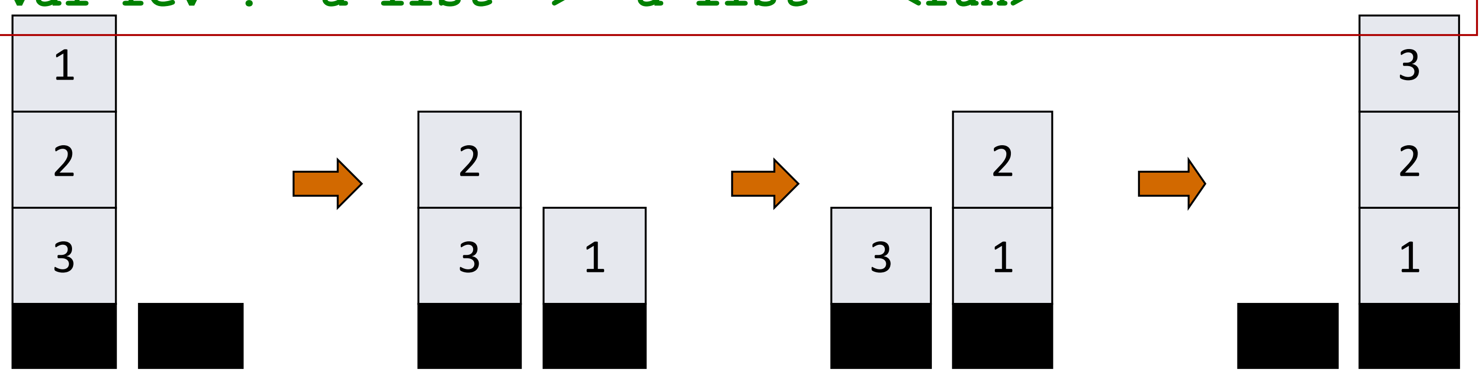
- Reverse a list

```
let rec reverse l =
    match l with
   | [] -> []
   | hd :: tl -> append (reverse tl)   [hd]
val reverse 'a list -> 'a list
```

- 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 arg =
      match arg with
      [] -> 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
val plus : int * int -> int = fun
```

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

```
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