Introduction to ML

Based on materials by
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ML

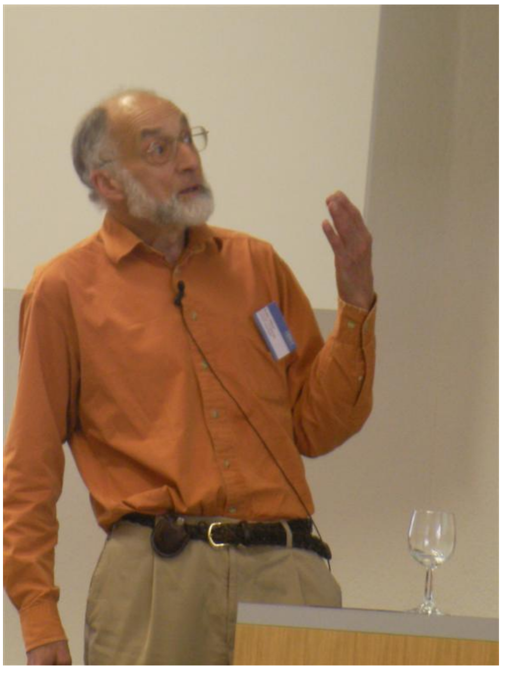
- General-purpose, non-C-like, non-OO language
  - Related languages: Haskell, Ocaml, F#, …
- Combination of Lisp and Algol-like features (1958)
  - Expression-oriented
  - Higher-order functions
  - Abstract data types
  - Module system
  - Exceptions
- Originally intended for interactive use

Why Study ML ?

ML is clean and powerful, and has many traits that language designers consider hallmarks of a good high-level language:

- Types and type checking
  - ML is a statically typed, strict **functional programming** language.
- Memory management
  - Static scope and block structure, activation records
  - Higher-order functions
- Garbage collection

History of ML



- Robin Milner
  - Stanford, U. of Edinburgh, Cambridge
  - 1991 Turing Award
- Logic for Computable Functions (LCF)
  - One of the first automated theorem provers
- Meta-Language of the LCF system

LCF – Logic of Computable Functions

ML was invented as part of the University of Edinburgh's LCF project, led by Robin Milner et al., who were conducting research in constructing automated theorem provers. Eventually observed that the "Meta Language" they used for proving theorems was more generally useful as a programming language.

Logic for Computable Functions

- Dana Scott (1969)
  - Formulated a logic for proving properties of typed functional programs
- Robin Milner (1972)
  - Project to automate logic
  - Notation for programs
  - Notation for assertions and proofs
  - Need to write programs that find proofs
    - Too much work to construct full formal proof by hand
  - Make sure proofs are correct

The interactive ML interpreter

- We'll use the Moscow ML implementation of ML97 (revision of the '80 Standard ML). Like most ML implementations, it provides a **read-eval-print loop** ("repl"), i.e. the interpreter repeatedly performs the following:
- **read**s an expression or declaration from standard input,
- **eval**uates the expression/declaration, and
- **print**s the value of expressions, or perhaps the type and initial value of declarations.

Basic Overview of ML

- Interactive compiler: read-eval-print
  - Compiler infers type before compiling or executing
  - No need for name declarations
- Examples

```
- (5+3)-2;
> val it = 6 : int
- if 5>3 then "Bob" else "Fido";
> val it = "Bob" : string
- 5=4;
> val it = false : bool
```

REPL

The primary advantage of programming in a repl is **immediate feedback**.

The read-eval-print cycle is *much* faster than the edit-compile-run cycle in a typical compiled programming environment.

You can quickly and easily experiment with different snippets of code. If a function doesn't work, you can try out a different version in a second or two, and re-run your program.

Basic Types

- Booleans
  - true, false : bool
  - if … then … else …   (types must match)
- Integers
  - 0, 1, 2, … : int
  - +, * , … : int * int → int   and so on …
- Strings
  - “Austin Powers”
- Reals
  - 1.0, 2.2, 3.14159, …   decimal point used to disambiguate

Compound Types

- Tuples
  - (4, 5, “noxious”) : int * int * string
    type
- Lists
  - nil
  - 1 :: [2, 3, 4]
- Records
  - {name = “Fido”, hungry=true}
    : {name : string, hungry : bool}
    type

Patterns and Declarations

- Patterns can be used in place of variables
  <pat> ::= <var> | <tuple> | <cons> | <record> …
- Value declarations
  - General form: val <pat> = <exp>
    val myTuple = (“Conrad”, “Lorenz”);
    val (x,y) = myTuple;
    val myList = [1, 2, 3, 4];
    val x::rest = myList;
  - Local declarations
    let val x = 2+3 in x*4 end;

Functions and Pattern Matching

- Anonymous function
  - fn x => x+1;   like function (…) in JavaScript
- Declaration form

  fun <name> <pat$_1$> = <exp$_1$>

  | <name> <pat$_2$> = <exp$_2$> …

  | <name> <pat$_n$> = <exp$_n$> …
- Examples
  - fun f (x,y) = x+y;   actual argument must match pattern (x,y)
  - fun length nil = 0

    | length (x::s) = 1 + length(s);

Functions on Lists

- Apply function to every element of list

  fun map (f, nil) = nil

  | map (f, x::xs) = f(x) :: map (f,xs);

  Example: map (fn x => x+1, [1,2,3]); ⇒ [2,3,4]
- Reverse a list

  fun reverse nil = nil

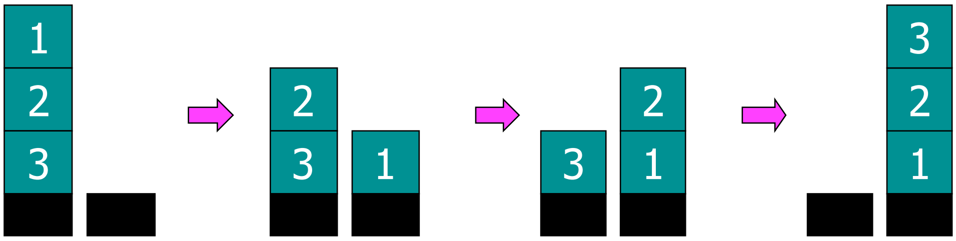
  | reverse (x::xs) = append ((reverse xs), [x]);
- Append lists

  fun append (nil, ys) = ys

  | append (x::xs, ys) = x :: append(xs, ys);

More Efficient Reverse Function

```
fun reverse xs =
    let fun rev(nil, z) = z
    |       rev(y::ys, z) = rev(ys, y::z)
    in rev( xs, nil )
end;
```



Datatype Declarations

- General form

  datatype <name> = <clause> | … | <clause>

  <clause> ::= <constructor> |<constructor> of <type>

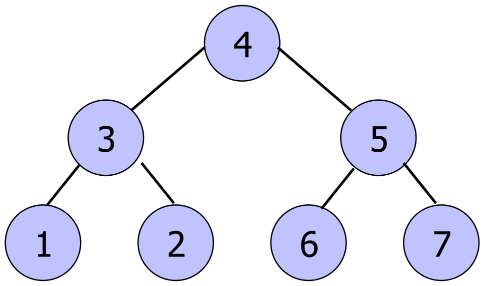
- Examples
  - datatype color = red | yellow | blue
    - Elements are red, yellow, blue
  - datatype atom = atm of string | nmbr of int
    - Elements are atm(“A”), atm(“B”), …, nmbr(0), nmbr(1), ...
  - datatype list = nil | cons of atom*list
    - Elements are nil, cons(atm(“A”), nil), …
      cons(nmbr(2), cons(atm(“ugh”), nil)), ...

Datatypes and Pattern Matching

◆ Recursively defined data structure

datatype tree = leaf of int | node of int*tree*tree

```
node(4, node(3,leaf(1), leaf(2)),
        node(5,leaf(6), leaf(7))
    )
```



◆ Recursive function

```
fun sum (leaf n) = n
|   sum (node(n,t1,t2)) = n + sum(t1) + sum(t2)
```


Example: Evaluating Expressions

◆ Define datatype of expressions

datatype exp = Var of int | Const of int | Plus of exp*exp;

Write (x+3)+y as Plus(Plus(Var(1),Const(3)), Var(2))

◆ Evaluation function

```
fun ev(Var(n)) = Var(n)
|   ev(Const(n)) = Const(n)
|   ev(Plus(e1,e2)) = …
```

ev(Plus(Const(3),Const(2))) ⇨ Const(5)

ev(Plus(Var(1),Plus(Const(2),Const(3)))) ⇨ ev(Plus(Var(1), Const(5))

Case Expression

- Datatype

  datatype exp = Var of int | Const of int | Plus of exp*exp;

- Case expression

```
case e of
    Var(n) =>  ...  |
    Const(n) => .... |
    Plus(e1,e2) => ...
```


Evaluation by Cases

```
datatype exp =  Var of int | Const of int | Plus of exp*exp;

fun ev(Var(n)) = Var(n)
|   ev(Const(n)) = Const(n)
|   ev(Plus(e1,e2)) =  (case ev(e1) of
          Var(n) => Plus(Var(n),ev(e2))      |
        Const(n) => (case ev(e2) of
                  Var(m) => Plus(Const(n),Var(m))     |
                Const(m) => Const(n+m)                |
              Plus(e3,e4) => Plus(Const(n),Plus(e3,e4)) )  |
    Plus(e3,e4) => Plus(Plus(e3,e4),ev(e2)) );
```

ML Imperative Features

- Remember l-values and r-values?
  - Assignment   y := x+3

    Refers to location (l-value)   Refers to contents (r-value)
- ML reference cells and assignment
  - Different types for location and contents

x : int	non-assignable integer value
y : int ref	location whose contents must be integer
!y	the contents of cell y
ref x	expression creating new cell initialized to x

  - ML form of assignment

y := x + 3	place value of x+3 in location (cell) y
y := !y + 3	add 3 to contents of y and store in location y

Reference Cells in ML

- Variables in most languages
  - Variable names a storage location
  - Contents of location can be read, can be changed
- ML reference cells
  - A mutable cell is another type of value
  - Explicit operations to read contents or change contents
  - Separates naming (declaration of identifiers) from "variables"

Imperative Examples in ML

- Create cell and change contents

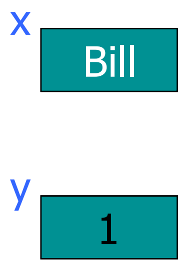
  ```
  val x = ref "Bob";
  x := "Bill";
  ```

- Create cell and increment

  ```
  val y = ref 0;
  y := !y + 1;
  ```

- "while" loop

  ```
  val i = ref 0;
  while !i < 10 do i := !i +1;
  !i;
  ```



Core ML

- Basic Types
  - Unit
  - Booleans
  - Integers
  - Strings
  - Reals
  - Tuples
  - Lists
  - Records
- Patterns
- Declarations ass name to exp
- Functions
- Polymorphism
- Overloading
- Type declarations
- Exceptions
- Reference cells

Related Languages

- ML family
  - Standard ML – Edinburgh, Bell Labs, Princeton, …
  - CAML, OCAML – INRIA (France)
    - Some syntactic differences from Standard ML (SML)
    - Object system
- Haskell
  - Lazy evaluation, extended type system, monads
- F#
  - ML-like language for Microsoft .NET platform
    - *"Combining the efficiency, scripting, strong typing and productivity of ML with the stability, libraries, cross-language working and tools of .NET. "*
  - Compiler produces .NET intermediate language