

# CS603 Programming Language Organization

Lecture 21

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# Objectives

- Provide you with some familiarity with ML. In particular, you should be able to:
  - Know how to use the immediate mode to perform simple calculations
  - Know how to load your own source files
  - Know how to use pattern matching in your functions
  - Know how to debug type errors

# ML

- Developed by Robert Milner circa 1975 for theorem proving.
- Began as a meta language (Logic of Computable Functions, LCF), and evolved into a full programming language.
- ML is a strongly typed functional language.
- Type checking is done by inferring types.
- Statically Type-checked
- ML is polymorphic.

# Data Types in ML

- int: 3, 4, 5, ~3, ~4, etc -- type int
- real: 3.14, 3.56, 0.03 -- type real
- bool: true, false -- type bool
- string: "foo", "boo" -- type string
- list: a sequence of homogeneous objects, [2,3,4] -- type int list, ["foo", "bar"] - type string list
- tuple: a sequence of heterogeneous objects ( abc,3,true) -- type string \* int \* bool
- function: fn (x, y) => x -- type int \* int -> int, (or type int \* real -> int, or type  $\tau_1 * \tau_2 \rightarrow \tau_1$ )

# Syntax of ML

- Variable definition:
- `val <var> = <expr>;`
- arithmetic operations are infix --
  - `4-x`
  - `9*(y+4)`
- if expression:
  - `if <expr> then <expr> else <expr>`
- let expression:
  - `let val x=3 val y=(3*5) in x*y;`

# Starting SML

## Immediate Mode

- Immediate mode statements must be terminated by a semicolon (;)
- The result is placed in the special variable `it`
- Notice the type inference!
- Moscow ML version 2.00 (June 2000)  
Enter `'quit();'` to quit.
  - `34 + 8;`
  - > `val it = 42 : int`
  - `it - 20;`
  - > `val it = 22 : int`
  -

# Hello, World

- Here is the Standard First Program
- The unit type is like void in C/C++; it represents commands.
- ```
- print "Hello, World!\n\n";  
Hello, World!  
  
> val it = () : unit  
-
```

# Some Simple Types

- ```
- 20.3;  
> val it = 20.3 : real  
- ~27  
> val it = ~27 : int  
- "Hi";  
> val it = "Hi" : string  
- (3, "x");  
> val it = (3, "x") : int *  
string  
-
```



# The List Type

- ```
> val it = [2.5,3.9,4.2] : real list
- hd it;
> val it = 2.5 : real
- 3 :: [2, 4];
> val it = [3,2,4] : int list
- tl it;
> val it = [2,4] : int list
- nil;
> val it = [] : 'a list
```

# List Manipulators

- `null` -- test whether a list is empty
- `hd` -- return the first element of a list
- `tl` -- return the list consisting of everything but the first element of its argument
- `::` -- `x::xs` is a list like `xs` but with `x` added at the beginning
- `@` -- infix append - join two lists together. (E.g. `[x]@xs` is the same thing as `x::xs`.)

# More about List Types

- Unlike tuples, all the elements of a list must have the same type.
- ```
- [3, 8.4];  
! Toplevel input:  
! [3, 8.4];  
!      ^^^  
! Type clash: expression of type  
!   real  
! cannot have type  
!   int  
-
```

# Variables

- - `val x = 20;`  
> `val x = 20 : int`  
- `x + 10;`  
> `val it = 30 : int`  
- `val x = 30;`  
> `val x = 30 : int`  
- `val y = 40 and s = "hi";`  
> `val y = 40 : int`  
`val s = "hi" : string`

# Functions

- fun name parameters = body ;
- - fun f x = x + 4;  
> val f = fn : int -> int  
- fun g x y = [x,y];  
> val g = fn : 'a -> 'a -> 'a list  
- f 30; (\* Functions are applied  
by juxtaposition! \*)  
> val it = 34 : int  
- g 20 5;  
> val it = [20,5] : int list

# Errors

```
• - fun f x = x + 4;  
> val f = fn : int -> int  
- f 6.3;  
! Toplevel input:  
! f 6.3;  
!   ^^^  
! Type clash: expression of type  
!   real  
! cannot have type  
!   int  
-
```

# More Errors

- ```
- fun g x y = [x,y];  
> val g = fn : 'a -> 'a -> 'a list  
- g "hi" 4.3;  
! Toplevel input:  
! g "hi" 4.3;  
!      ^^^  
! Type clash: expression of type  
!   real  
! cannot have type  
!   string
```
- -Always always ask ``what are the types?''!
- That habit will save you a lot of time!

# Recursive Functions

- ```
- fun f n =  
    if (n = 0)  
    then 1  
    else 1 + (f (n - 1));  
> val f = fn : int -> int  
- f 10;  
> val it = 11 : int  
-
```



# Function Definition

- Syntax:

- `val [rec] <name> = fn <tuple> => <expr>`

- `fun <name> <arg-pat> = <expr1> | ...`

- Examples

- `val identity = fn x => x`

- `val rec fact = fn x => if x <= 1`

- `then 1`

- `else x * (fact (x - 1));`

- `fun fact x = if x <= 1 then 1`

- `else x * (fact (x - 1));`



equivalent



# Function Application

- Syntax:
  - $f(a, b, c)$  -- equivalent to same call in C.
  - $f\ a\ b\ c$  -- equivalent to  $((f\ a)\ b)\ c$  (called curried form)
- Function application associates to the left.
- Use parentheses if you want to change the association.

# Pattern Matching

- ```
- fun f 0 = 1
      | f n = 1 + f (n-1);
> val f = fn : int -> int
- f 10;
> val it = 11 : int
-
```
- Notice the similarity to a mathematical definition.

# Pattern Matching II

- Function `f` takes a tuple as its argument.
- Function `g` takes two arguments. Don't confuse them!
- - `fun f (a,b) = a + b;`
  - > `val f = fn : int * int -> int`
  - `f (10,30);`
  - > `val it = 40 : int`
  - `fun g a b = a + b;`
  - > `val g = fn : int -> int -> int`
  - `g 10 20;`
  - > `val it = 30 : int`
  -

# Pattern Matching III

- ```
- fun f [] = 0
  | f (x::xs) = 1 + (f xs);
> val f = fn : 'a list -> int
- f [10,20,30,40];
> val it = 4 : int
-
```
- Can you explain what this function is doing? What is the type of `x`? What is the type of `xs`?

# Mystery I

- ```
- fun f 0 = 0
      | f 1 = 1
      | f n = f (n-1) + f (n-2);
> val f = fn : int -> int
- (f 3, f 5, f 8);
> val it = (2,5,21) : int *
int * int
```

# Mystery 2

- - fun f [] = 0  
    | f (x::xs) = x + f xs;  
> val f = fn : int list -> int  
- f [10,10,10,12];  
> val it = 42 : int  
-

# Mystery 3

- - 

```
fun f [] = []  
  | f (x::xs) =  
      if (x < 5)  
      then f xs  
      else x :: f xs;  
  
> val f = fn : int list -> int list  
- f [1,5,10,3,4,48];  
> val it = [5,10,48] : int list  
-
```



# Mystery 4

- ```
- fun f 0 a = []
  | f n a = a :: (f (n-1) (a-1));
> val f = fn : int -> int -> int list
- f 6;
> val it = fn : int -> int list
- it 10;
> val it = [10,9,8,7,6,5] : int
list
-
```

# Bonus!

- Higher Order Functions!

- ```
- fun twice f x = f (f x);  
> val twice = fn : ('a -> 'a) -> 'a  
-> 'a  
- fun inc n = n + 1;  
> val inc = fn : int -> int  
- twice inc 20;  
> val it = 22 : int  
-
```

# One more thing....

- - use "myprogram.sml";
- Immediate mode is fun, but it can be counter-productive....

# Recursion in ML

- In functional languages, repetition is accomplished by recursion.
- ```
fun gcd m n =  
  if m = n then m  
  else if m < n then gcd m (n % m)  
  else gcd n m;
```

# Lists

- Recursive data structure:
  - A  $\alpha$  list (a list whose elements are of type  $\alpha$ ) is either empty or a  $\alpha$  joined to a  $\alpha$  list.
- If  $L = x$  joined to  $M$ , then  $x$  is the head of  $L$  and  $M$  is the tail of  $L$

# Lists in ML

- Constants:
  - `[1,2,3]: int list`
  - `[true, false]: bool list`
- Operations:
  - `hd [1,2,3] = 1`
  - `tl [1,2,3] = [2,3]`
  - `null [] = true`
  - `null [1,2] = false`
  - `1::[2,3] = [1,2,3]`

# Types of ML lists and operations

- Lists can contain other lists, but are homogeneous.
  - `[[1,2], [], [4,5,2]]`: `(int list) list`
- But `[1, [2,3]]` is not legal.
- List operations have polymorphic types:
  - `hd: 'a list -> 'a`
  - `tl: 'a list -> 'a list`
  - `::: 'a * 'a list -> 'a list`
  - `null: 'a list -> bool`

# Simple examples

- ```
fun tltl L = (tl (tl L));
fun hdtl L = hd (tl L);
fun incrhd L = (1+(hd L))::(tl L);
fun swaphd L =
    (hdtl L) :: (hd L) :: (tltl L);
fun length L = if null L then 0
               else 1+(length (tl L));
fun append L M = if null L then M
                 else (hd L)::(append (tl L) M);
fun concat L M = if null L then L
                  else (append (hd L) M);
```



# Pattern-matching in function definitions

- `fun f [] = ...`
  - | `f (x::xs) = ...x...(f xs)...`
- `fun f [] M = ...M...`
  - | `f L [] = ...L...`
  - | `f (x::xs) (y::ys) =`
    - `...x...y...(f xs ys)...`
- `fun f [] = ...`
  - | `f [x] = ...x...`
  - | `f (x::y::xs) =`
    - `...x...y...(f (y::xs))...`

# Example: merge sort

- ```
fun msort L =  
  let val halves = split L  
  in merge (msort (hd halves))  
           (msort (hdtl halves))  
  end  
  
fun split [] = [[], []]  
  | split [a] = [[a], []]  
  | split (a::b::t) =  
    let val splittl = split t  
    in [a::(hd splittl),  
        b::(hdtl splittl)]  
    end;
```

# Algebraic Data-types

- ```
datatype 'a tree = Empty
                | Node of 'a tree *
                          'a *
                          'a tree
```

```
fun height Empty = 0
  | height (Node (lft, _, rht)) =
    1 + max (height lft, height rht)
```

# Resources

- “Programming in Standard ML”
  - <http://www-2.cs.cmu.edu/~rwh/smlbook/offline.pdf>
- Source code from above book
  - <http://www-2.cs.cmu.edu/~rwh/smlbook/examples/>
- Moscow ML
  - <http://www.dina.dk/~setsoft/mosml.html>