ML

CSCI 334
Stephen Freund

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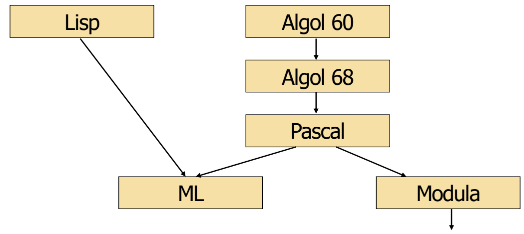
Language History



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Algol 60

```
real procedure average(A,n);
 real array A; integer n;
 begin
     real sum;
     sum := 0;
     for i = 1 step 1 until n do
       sum := sum + A[i];
     average := sum/n
 end;
```

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ML

- Combination of Lisp and Algol-like features

- Expression-oriented
- Higher-order functions
- Garbage collection

- **Static types**
- **Abstract data types**
- **Module system**
- **Exceptions**

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Goals in study of ML

- Types, type checking, polymorphism

- Memory management

- Control Structures

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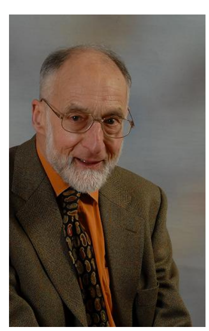
Robin Milner and ML's Origins



- Dana Scott, 1969
  - LCF
  - logic for stating theorems about programs

- Robin Milner
  - automated theorem proving for LCF
  - Hard search problem
  - Incomplete: may not find proof
  - ML: meta-language for writing programs (tactics) to find proofs

Dafny Example

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Tactics

- Tactics guide search in theorem prover
  - "Try induction to prove T"
  - "Assume X and derive contradiction"
  - "Try A and then B"
- Tactic is *partial* function from formula -> proof
  - finds proof
  - never terminates
  - reports an error

Language Ideas to Support Tactics

- Type system
  - guarantees correctness of generated proof
- Exception handling
  - deals with tactics that fail (Turing Award)
- Higher-order functions
  - composition of tactics
  - fun compose(t1, t2) =

    λformula. if t1(formula) then ...

    else if t2(formula) ...

Running ML

- Type **sml** on Unix machines
- System will give you prompt
- Enter expression or declarations to evaluate:

```
- 3 + 5;
val it = 8 : int
- it * 2;
val it = 16 : int
- val six = 3 + 3;
val six = 6 : int
```

- Or "**sml < file.ml**"

Defining Functions

No type info given- compiler infers it

- Example

```
- fun succ x = x + 1;
val succ = fn : int -> int
- succ 12;
val it = 13 : int
- 17 * (succ 3);
val it = 68 : int;
```

- Or:

```
- val succ = fn x => x + 1;
val succ = fn : int -> int
```


Recursion

- All functions written using recursion and if.. then.. else (and patterns):

```
- fun fact n =
    if n = 0 then 1 else n * fact (n-1);
```

- if..then..else is an expression:

```
- if 3<4 then "moo" else "cow";
val it = "moo" : string
```

  - types of branches must match

Local Declarations

```
- fun cylinderVolume diameter height =
    let val radius = diameter / 2.0;
        fun square y = y * y
    in
        3.14 * square(radius) * height
    end;

val cylinderVolume = fn : real -> real -> real

- cylinderVolume 6.0 6.0;
val it = 169.56 : real
```

Built-in Data Types

- unit
  - only value is `()`
- bool
  - `true, false`
  - operators `not, andalso, orelse`
- int
  - ..., `~2, ~1, 0, 1, 2,` ...
  - `+,-,*,div,mod,abs`
  - `=,<,<=`, etc.

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Built-in Data Types

- real
  - 3.17, 2.2, ...
  - `+, -, *, /`
  - `<, <=`, etc.
  - no conversions from int to real: 2 + 3.3 is bad
  - no equality (test that -0.001 < x-y < 0.001, etc.)
- strings
  - "moo"
  - "moo" ^ "cow"

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Overloaded Operators

- +,-,etc. defined on both int and real
- Which one to use depends on operands:

```
- fun succ x = x + 1
val succ = fn : int -> int

- fun double x = x * 2.0
val double = fn : real -> real

- fun double x = x + x
val double = fn : int -> int
```

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Type Declarations

- Can add types when type inference does not work

```
- fun double (x:real) = x + x;
val double = fn : real -> real

- fun double (x:real) : real = x + x;
val double = fn : real -> real
```

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Compound Types

- Tuples, Records, Lists
- Tuples

```
(14, "moo", true): int * string * bool
```

- Functions can take tuple argument

```
- fun power (exp,base) =
    if exp = 0 then 1
      else base * power(exp-1,base);
val power = fn : int * int -> int
- power(3,2);
```

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Curried Functions (named after Curry)

- Previous power

```
- fun power (exp,base) =
    if exp = 0 then 1
       else base * power(exp-1,base);
val power = fn : int * int -> int
```

- Curried power function

```
- fun cpower exp =
    fn base =>
      if exp = 0 then 1
         else base * cpower (exp-1) base;

val cpower = fn : int -> (int -> int)
```

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Curried Functions (named after Curry)

- Previous power

```
- fun power (exp,base) =
      if exp = 0 then 1
         else base * power(exp-1,base);
val power = fn : int * int -> int
```

- Curried power function

```
- fun cpower exp base =
       if exp = 0 then 1
          else base * cpower (exp-1) base;

val cpower = fn : int -> (int -> int)
```


Curried Functions

- Why is this useful?

```
- fun cpower exp base =
      if exp = 0 then 1
         else base * cpower (exp-1) base;
val cpower = fn : int -> (int -> int)
```

- Can define

```
- val square = cpower 2
val square = fn : int -> int
- square 3;
val it = 9 : int
```


Records

- Like tuple, but with labeled elements:

```
{ name="Gus", salary=3.33, id=11 }:
  { name:string, salary:real, id:int };
```

- Selector operator:

```
- val x =
     { name="Gus", salary=3.33, id=11 };
- #salary(x);
val it = 3.33 : real
- #name(x);
val it = "Gus" : string
```


Lists

- Examples
  - [1, 2, 3, 4], ["wombat", "numbat"]
  - nil is empty list (sometimes written [])
  - all elements must be same type
- Operations
  - length `length [1,2,3]` ⇒ `3`
  - @ - append `[1,2]@[3,4]` ⇒ `[1, 2, 3, 4]`
  - :: - prefix `1::[2,3]` ⇒ `[1, 2, 3]`
  - map `map succ [1,2,3]` ⇒ `[2,3,4]`

Lists

- Functions on Lists

```
- fun product (nums) =
    if (nums = nil)
      then 1
      else (hd nums) * product(tl nums);

val product = fn : int list -> int

- product([5, 2, 3]);
val it = 30 : int;
```


Pattern Matching

- List is one of two things:
  - nil
  - "first elem" :: "rest of elems"
  - [1, 2, 3] = 1::[2,3] = 1::2::[3] = 1::2::3::nil
- Can define function by cases

```
fun product (nil) = 1
  | product (x::xs) = x * product (xs);
```

Patterns on Integers

- Patterns on integers

```
fun listInts 0 = [0]
  | listInts n = n::listInts(n-1);

listInts 3 ⇒ [3, 2, 1, 0];
```

- More on patterns for other data types next time

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Many Types Of Lists

- `1::2::nil : int list`
  `"wombat"::"numbat"::nil : string list`
- What type of list is `nil`?

```
- nil;
val it = [] : 'a list
```

- Polymorphic type
  - `'a` is a type variable that represents any type
  - `1::nil : int list`
    `"a"::nil : string list`

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The Length Function

- Another Example

```
fun length (nil) = 0
  | length (x::xs) = 1 + length (xs);
```

- What is the type of length?
- How about this one:

```
fun id x = x;
```

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Polymorphism

```
fun length (nil) = 0
  | length (x::xs) = 1 + length (xs);
- val it = fun 'a list -> int

fun id x = x;
- val it = fun 'a -> 'a
```

Type variable represents any type

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Patterns and Other Declarations

- Patterns can be used in place of variables
- Most basic pattern form
  - `val <pattern> = <exp>;`
- Examples
  - `val x = 3;`
  - `val tuple = ("moo", "cow");`
  - `val (x,y) = tuple;`
  - `val myList = [1, 2, 3];`
  - `val w::rest = myList;`
  - `val v::_ = myList;`

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Datatype

```
public static final int NORTH = 1;
public static final int SOUTH = 2;
public static final int EAST = 3;
public static final int WEST = 4;

public move(int x, int y, int dir) {
  switch (dir) {
    case NORTH: ...
    case ...
  }
}
```

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Datatype

```
datatype Direction =
     NORTH | SOUTH | EAST | WEST;

fun move((x,y),NORTH) = (x,y-1)
  | move((x,y),SOUTH) = (x,y+1)
  ...
  ;
```

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