CS 242

The Algol Family and ML

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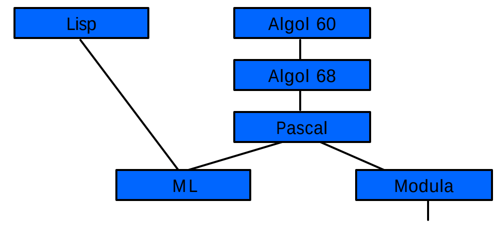
Language Sequence



Many other languages:
Algol 58, Algol W, Euclid, EL1, Mesa (PARC), ...
Modula-2, Oberon, Modula-3 (DEC)

Algol 60

- Basic Language of 1960
  - Simple imperative language + functions
  - Successful syntax, BNF -- used by many successors
    - statement oriented
    - Begin ... End blocks (like C { ... })
    - if ... then ... else
  - Recursive functions and stack storage allocation
  - Fewer ad hoc restrictions than Fortran
    - General array references: A[x + B[3]*y]
  - Type discipline was improved by later languages
  - Very influential but not widely used in US

Algol 60 Sample

```
real procedure average(A,n);
  real array A; integer n;          —— no array bounds
  begin
     real sum; sum := 0;
     for i = 1 step 1 until n do
          sum := sum + A[i];
     average := sum/n               —— no ; here
  end;
```

set procedure return value by assignment

Algol Joke

- Question
  - Is x := x equivalent to doing nothing?
- Interesting answer in Algol

```
integer procedure p;
begin
     ....
     p := p
     ....
 end;
```

  - Assignment here is actually a recursive call

Some trouble spots in Algol 60

- Type discipline improved by later languages
  - parameter types can be array
    - no array bounds
  - parameter type can be procedure
    - no argument or return types for procedure parameter
- Parameter passing methods
  - Pass-by-name had various anomalies
    - "Copy rule" based on substitution, interacts with side effects
  - Pass-by-value expensive for arrays
- Some awkward control issues
  - goto out of block requires memory management

Algol 60 Pass-by-name

- Substitute text of actual parameter
  - Unpredictable with side effects!
- Example

```
procedure inc2(i, j);
  integer i, j;
  begin
    i := i+1;
    j := j+1
  end;
inc2 (k, A[k]);
```

→

```
begin
  k := k+1;
  A[k] := A[k] +1
end;
```

Is this what you expected?

Algol 68

- Considered difficult to understand
  - Idiosyncratic terminology
    - types were called “modes”
    - arrays were called “multiple values”
  - vW grammars instead of BNF
    - context-sensitive grammar invented by A. van Wijngaarden
  - Elaborate type system
  - Complicated type conversions
- Fixed some problems of Algol 60
  - Eliminated pass-by-name
- Not widely adopted

Algol 68 Modes

- Primitive modes
  - int
  - real
  - char
  - bool
  - string
  - compl (complex)
  - bits
  - bytes
  - sema (semaphore)
  - format (I/O)
  - file
- Compound modes
  - arrays
  - structures
  - procedures
  - sets
  - pointers

Rich and structured type system is a major contribution of Algol 68

Other features of Algol 68

- Storage management
  - Local storage on stack
  - Heap storage, explicit alloc and garbage collection
- Parameter passing
  - Pass-by-value
  - Use pointer types to obtain Pass-by-reference
- Assignable procedure variables
  - Follow “orthogonality” principle rigorously

Source: Tanenbaum, Computing Surveys

Pascal

- Revised type system of Algol
  - Good data-structuring concepts
    - records, variants, subranges
  - More restrictive than Algol 60/68
    - Procedure parameters cannot have procedure parameters
- Popular teaching language
- Simple one-pass compiler

Limitations of Pascal

- Array bounds part of type

```
procedure p(a : array [1..10] of integer)
procedure p(n: integer, a : array [1..n] of integer)
```

illegal

  - Attempt at orthogonal design backfires
    - parameter must be given a type
    - type cannot contain variables

  How could this have happened? Emphasis on teaching
- Not successful for “industrial-strength” projects
  - Kernighan -- Why Pascal is not my favorite language
  - Left niche for C; niche has expanded!!

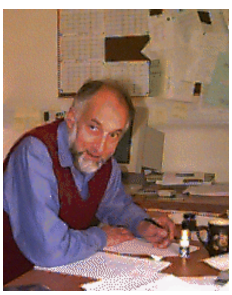
ML

- Typed programming language
- Intended for interactive use
- Combination of Lisp and Algol-like features
  - Expression-oriented
  - Higher-order functions
  - Garbage collection
  - Abstract data types
  - Module system
  - Exceptions
- General purpose non-C-like, not OO language

Goals in study of ML

- Survey a modern procedural language
- Discuss general programming languages issues
  - Types and type checking
    - General issues in static/dynamic typing
    - Type inference
    - Polymorphism and Generic Programming
  - Memory management
    - Static scope and block structure
    - Function activation records, higher-order functions
  - Control
    - Force and delay
    - Exceptions
    - Tail recursion and continuations

History of ML



- Robin Milner
- Logic for Computable Functions
  - Stanford 1970-71
  - Edinburgh 1972-1995
- Meta-Language of the LCF system
  - Theorem proving
  - Type system
  - Higher-order functions

Logic for Computable Functions

- Dana Scott, 1969
  - Formulate logic for proving properties of typed functional programs
- Milner
  - 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

LCF proof search

- Tactic: function that tries to find proof

tactic(formula) = { succeed and return proof; search forever; fail }

- Express tactics in the Meta-Language (ML)
- Use type system to facilitate correctness

Tactics in ML type system

- Tactic has a functional type

  tactic : formula → proof

- Type system must allow “failure”

tactic(formula) = { succeed and return proof; search forever; fail and *raise exception* }

Function types in ML

f : A → B   means

for every x ∈ A,

f(x) = { some element y=f(x) ∈ B / run forever / terminate by raising an exception }

In words, "if f(x) terminates normally, then f(x)∈ B."

Addition never occurs in f(x)+3 if f(x) raises exception.

This form of function type arises directly from motivating application for ML. Integration of type system and exception mechanism mentioned in Milner's 1991 Turing Award.

Higher-Order Functions

- Tactic is a function
- Method for combining tactics is a function on functions
- Example:

  f($tactic_1$, $tactic_2$) =

  λ formula. try $tactic_1$(formula)

  else $tactic_2$ (formula)

Basic Overview of ML

- Interactive compiler: *read-eval-print*
  - Compiler infers type before compiling or executing

    Type system does not allow casts or other loopholes.
- 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
```

Overview by Type

- 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
- Lists
  - nil
  - 1 :: [2, 3, 4]   infix cons notation
- Records
  - {name = "Fido", hungry=true}

    : {name : string, hungry : bool}

Patterns and Declarations

- Patterns can be used in place of variables

  <pat> ::= <var> | <tuple> | <cons> | <record> …
- Value declarations
  - General form

    val <pat> = <exp>
  - Examples

    ```
    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 Lisp lambda
- 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 par must match pattern (x,y)
  - fun length nil = 0
    | length (x::s) = 1 + length(s);

Map function on lists

- Apply function to every element of list

```
fun map (f, nil) = nil
|   map (f, x::xs) = f(x) :: map (f,xs);

    map (fn 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

- Reverse a list

```
fun reverse nil = nil
|     reverse (x::xs) = append ((reverse xs), [x]);
```

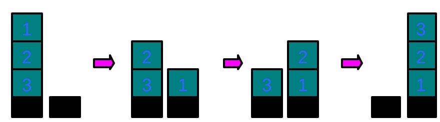
- Append lists

```
fun append(nil, ys) = ys
|     append(x::xs, ys) = x :: append(xs, ys);
```

- Questions
  - How efficient is reverse?
  - Can you do this with only one pass through list?

More efficient reverse function

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



Datatype Declarations

- General form

datatype <name> = <clause> | ... | <clause>

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

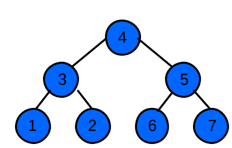
- Examples
  - datatype color = red | yellow | blue
    - elements are red, yellow, blue
  - datatype atom = atm of string | nmbr of int
    - elements are atm("A"), atm("B"), ..., nmbr(0), nmbr(1), ...
  - datatype list = nil | cons of atom*list
    - elements are nil, cons(atm("A"), nil), ...
    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

Datatype 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)) = ...
```

Examples

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)) );
```

Core ML

- Basic Types
  - Unit
  - Booleans
  - Integers
  - Strings
  - Reals
  - Tuples
  - Lists
  - Records
- Patterns
- Declarations
- Functions
- Polymorphism
- Overloading
- Type declarations
- Exceptions
- Reference Cells

Variables and assignment

- General terminology: L-values and R-values
  - Assignment y := x+3
    - Identifier on left refers to a memory location, called L-value
    - Identifier on right refers to contents, called R-value
- Variables
  - Basic properties
    - A variable names a storage location
    - Contents of location can be read, can be changed
  - ML
    - A variable is another type of value
    - Explicit operations to read contents or change contents
    - Separates naming (declaration of identifiers) from "variables"

ML imperative constructs

- ML reference cells
  - 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 location y
ref x	expression creating new cell initialized to x

  - ML assignment
    - operator := applied to memory cell and new contents
  - Examples

y := x+3	place value of x+3 in cell y; requires x:int
y := !y + 3	add 3 to contents of y and store in location y

ML examples

- 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;
```