The Algol Family and ML

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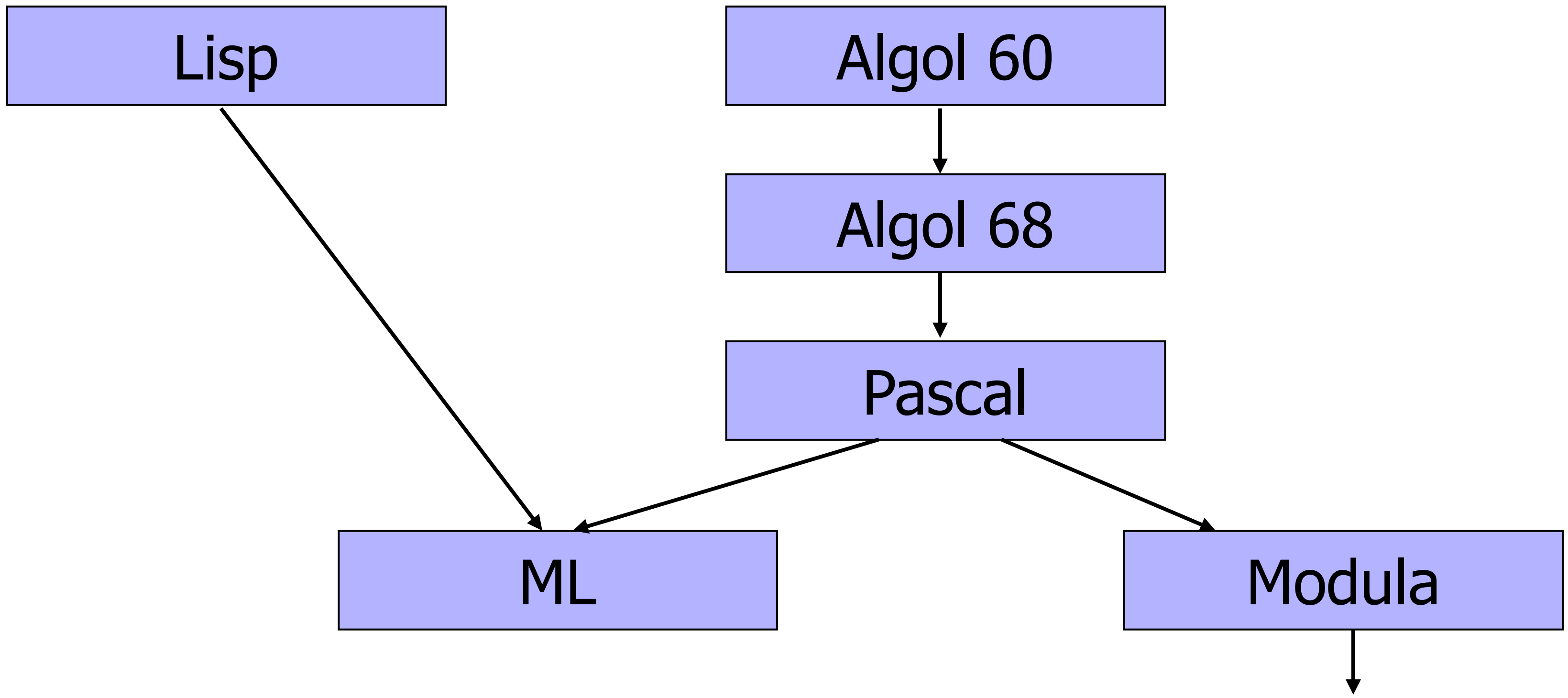
Reading: Chapter 5

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;
  begin
     real sum; sum := 0;
     for i = 1 step 1 until n do
          sum := sum + A[i];
     average := sum/n
  end;
```

no array bounds

no ; here

set procedure return value by assignment

Algol oddity

- 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 other issues

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
  - Strange 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

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

  illegal

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

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

  - parameter must be given a type
  - type cannot contain variables

- Not successful for “industrial-strength” projects

C Programming Language

Designed by Dennis Ritchie for writing Unix

- Evolved from B, which was based on BCPL
  - B was an untyped language; C adds some checking
- Relation between arrays and pointers
  - An array is treated as a pointer to first element
  - E1[E2] is equivalent to ptr dereference *((E1)+(E2))
  - Pointer arithmetic is *not* common in other languages
- Ritchie quote
  - "C is quirky, flawed, and a tremendous success."

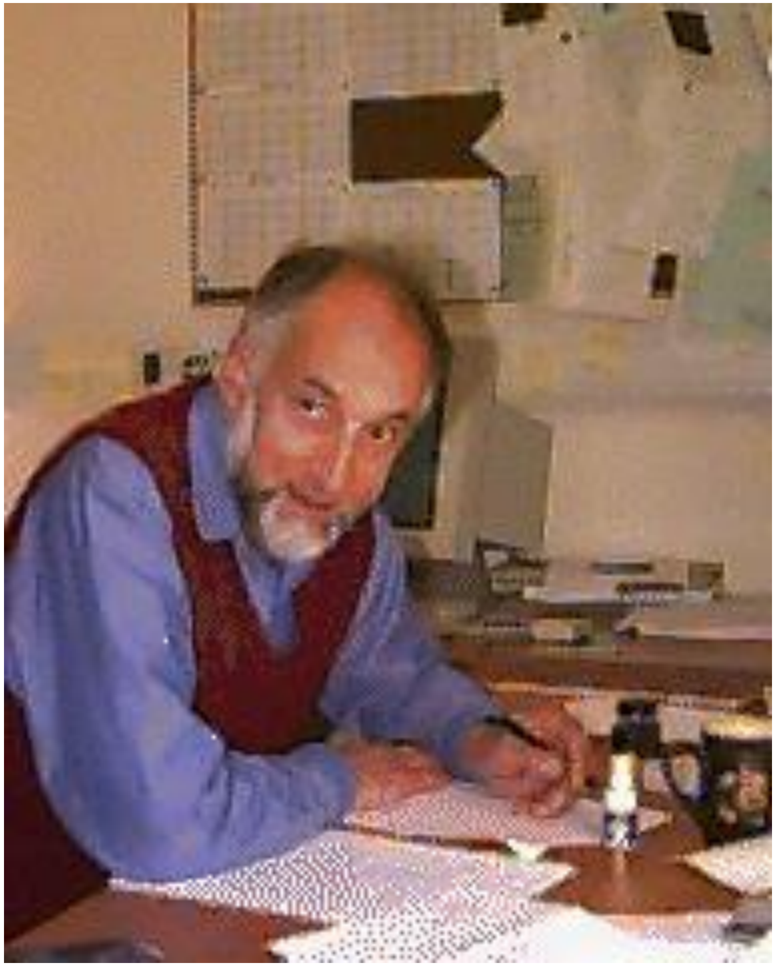
ML

- 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
  - Related languages: Haskell, OCAML, F#, …

Why study ML ?

- 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

- 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

$$\text{tactic(formula)} = \begin{cases} \text{succeed and return proof} \\ \text{search forever} \\ \text{fail} \end{cases}$$

Tactics in ML type system

- Tactic has a functional type

  tactic : formula $\rightarrow$ proof

- Type system must allow "failure"

$$\text{tactic(formula)} = \begin{cases} \text{succeed and return proof} \\ \text{search forever} \\ \text{fail and } \textit{raise exception} \end{cases}$$

Function types in ML

$f : A \to B$ means

for every $x \in A$,

$$f(x) = \begin{cases} \text{some element } y = f(x) \in B \\ \text{run forever} \\ \text{terminate by raising an exception} \end{cases}$$

In words, "if f(x) terminates normally, then $f(x) \in B$."

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:

$f(\text{tactic}_1, \text{tactic}_2) =$

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
  - "Hello World!"
- 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, function (…) in JS
- 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]);
```

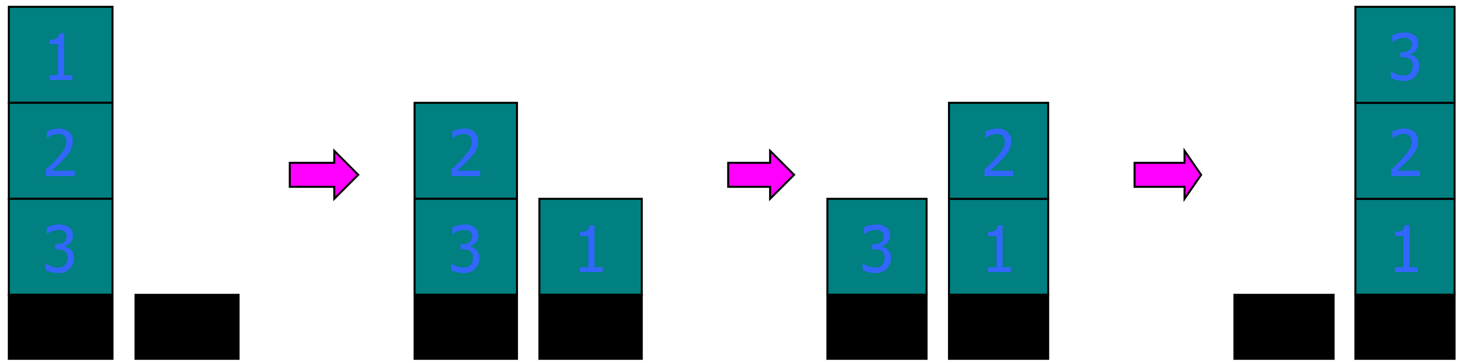
- Append lists

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



Datatype Declarations

- General form

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

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

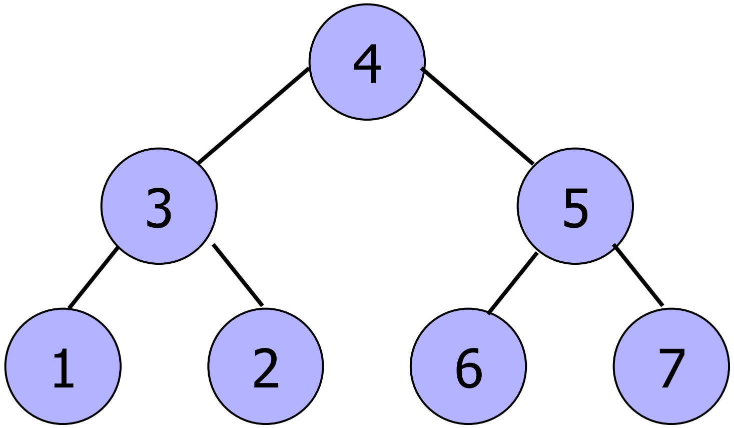
- Examples
  - datatype color = red | yellow | blue
    - elements are red, yellow, blue
  - datatype atom = atm of string | nmbr of int
    - elements are atm("A"), atm("B"), …, nmbr(0), nmbr(1), ...
  - datatype list = nil | cons of atom*list
    - elements are nil, cons(atm("A"), nil), …
      cons(nmbr(2),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

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
  - Most languages
    - A variable names a storage location
    - Contents of location can be read, can be changed
  - ML reference cell
    - A mutable cell 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

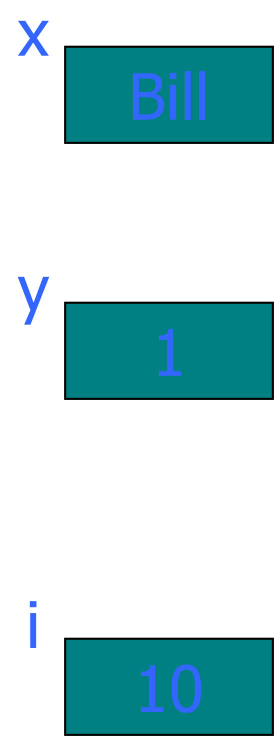
```
val x = ref "Bob";
x := "Bill";
```

- 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;
```



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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 IL intermediate language