A restriction that made Pascal simpler than Algol 68:

```
procedure
  Allowed( j,k: integer );

procedure
  AlsoAllowed( procedure P(i:integer);
                 j,k: integer );

procedure
  NotAllowed( procedure
    MyProc( procedure
      P( i:integer ) ) );
```

allows static type checking

⇝ fails orthogonality

- Pascal was the first language to propose index checking.
- Problematically, in Pascal, the index type of an array is part of its type. The Pascal standard defines *conformant array parameters* whose bounds are implicitly passed to a procedure. The Ada programmig language uses so-called *unconstrained array types* to solve this problem.

  The subscript range must be fixed at compile time permitting the compiler to perform all address calculations during compilation.

$$\texttt{procedure Allowed(a: }\underbrace{\texttt{array [1..10] of integer}}_{\neq\ \texttt{array [0..9] of integer}}\texttt{) ;}$$

```
procedure
  NotAllowed( n: integer;
              a: array [1..n] of integer ) ;
```

- Pascal uses a mixture of *name* and *structural* equivalence for determining if two variables have the same type.

  Name equivalence is used in most cases for determining if formal and actual parameters in subprogram calls have the same type; structural equivalence is used in most other situations.

- Parameters are passed by value or reference.

  Complete static type checking is possible for correspondence of actual and formal parameter types in each subprogram call.

Pascal variant records

Variant records have a part common to all records of that type, and a variable part, specific to some subset of the records.

```
type
kind = ( unary, binary) ;
type                        { datatype                       }
UBtree = record             {     'a UBtree = record of      }
  value: integer ;          {          'a * 'a UBkind        }
  case k: kind of           { and 'a UBkind =                }
    unary: ^UBtree ;        {           unary of 'a UBtree   }
    binary: record          {         | binary of            }
      left: ^UBtree ;       {             'a UBtree *        }
      right: ^UBtree        {             'a UBtree ;        }
      end
end ;
```

Variant records introduce *weaknesses* into the type system for a language.

1. Compilers do not usually check that the value in the tag field is consistent with the state of the record.

2. Tag fields are optional. If omitted, no checking is possible at run time to determine which variant is present when a selection is made of a field in a variant.

Note that datatype and case in ML effectively provide a safe form of variant records. Why are they safe?

Summary

- The Algol family of languages established the command-oriented syntax, with blocks, local declarations, and recursive functions, that are used in most current programming languages.
- The Algol family of languages is statically typed, as each expression has a type that is determined by its syntactic form and the compiler checks before running the program to make sure that the types of operations and operands agree.

∼ Topic V ∼

Object-oriented languages : Concepts and origins SIMULA and Smalltalk

References:

- ⋆ **Chapters 10 and 11** of *Concepts in programming languages* by J. C. Mitchell. CUP, 2003.
- ♦ **Chapters 8, and 12(§§2 and 3)** of *Programming languages: Design and implementation* (3RD EDITION) by T. W. Pratt and M. V. Zelkowitz. Prentice Hall, 1999.

- ♦ **Chapter 7** of *Programming languages: Concepts & constructs* by R. Sethi (2ND EDITION). Addison-Wesley, 1996.
- ♦ **Chapters 14 and 15** of *Understanding programming languages* by M Ben-Ari. Wiley, 1996.
- ⋆ B. Stroustrup. What is "Object-Oriented Programming"? (1991 revised version). Proc. 1st European Conf. on Object-Oriented Programming. (Available on-line from `<http://public.research.att.com/~bs/papers.html>`.)

Objects in ML !?

```
exception Empty ;
fun newStack(x0)
  = let val  stack = ref [x0]
    in ref{  push = fn(x)
               => stack := ( x :: !stack )     ,
             pop = fn()
               => case !stack of
                    nil => raise Empty
                  | h::t => ( stack := t; h )
    }end ;
exception Empty
val newStack = fn :
      'a -> {pop:unit -> 'a, push:'a -> unit} ref
```

```
val BoolStack = newStack(true) ;

val BoolStack = ref {pop=fn,push=fn}
  : {pop:unit -> bool, push:bool -> unit} ref

val IntStack0 = newStack(0) ;

val IntStack0 = ref {pop=fn,push=fn}
  : {pop:unit -> int, push:int -> unit} ref

val IntStack1 = newStack(1) ;

val IntStack1 = ref {pop=fn,push=fn}
  : {pop:unit -> int, push:int -> unit} ref
```

```
IntStack0 := !IntStack1 ;
```

NB aliasing

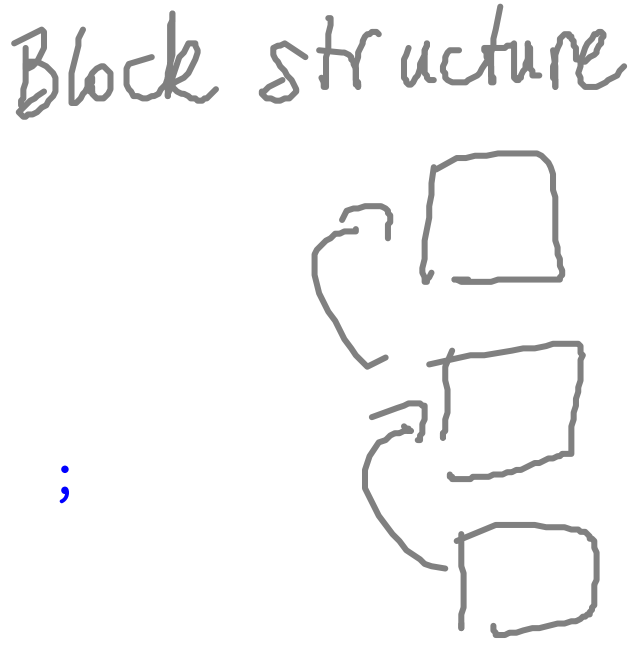
```
val it = () : unit

#pop(!IntStack0)() ;

val it = 1 : int

#push(!IntStack0)(4) ;

val it = () : unit
```

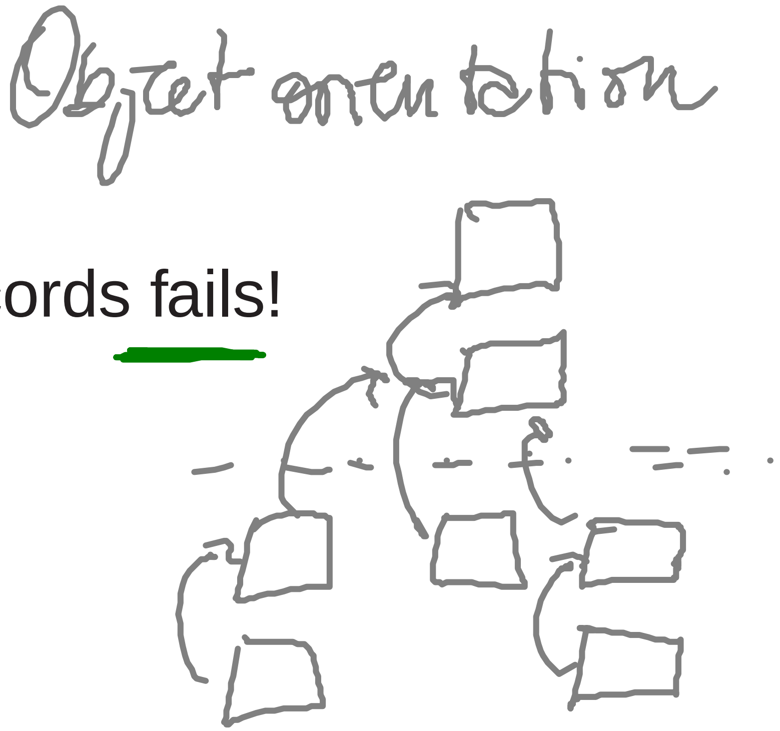


```
map ( #push(!IntStack0) ) [3,2,1] ;

val it = [(),(),()] : unit list

map ( #pop(!IntStack0) ) [(),(),(),()] ;

val it = [1,2,3,4] : int list
```



NB:

- $\boxed{!}$ The *stack discipline* for activation records fails!
- $\boxed{?}$ Is ML an object-oriented language?

  $\boxed{!}$ Of course not!

  $\boxed{?}$ Why?

Basic concepts in object-oriented languages[a]

Four main language concepts for object-oriented languages:

1. Dynamic lookup.
2. Abstraction.
3. Subtyping.
4. Inheritance.

[a]Notes from **Chapter 10** of *Concepts in programming languages* by J. C. Mitchell. CUP, 2003.

Dynamic lookup

- *Dynamic lookup* means that when a message is sent to an object, the method to be executed is selected dynamically, at run time, according to the implementation of the object that receives the message. In other words, the object "chooses" how to respond to a message.

  The important property of dynamic lookup is that different objects may implement the same operation differently, and so may respond to the same message in different ways.

done statically

- Dynamic lookup is sometimes confused with overloading, which is a mechanism based on *static types* of operands. However, the two are very different. $\boxed{\textbf{?}}$ Why?

Abstraction

- *Abstraction* means that implementation details are hidden inside a program unit with a specific interface. For objects, the interface usually consists of a set of methods that manipulate hidden data.

- Abstraction based on objects is similar in many ways to abstraction based on abstract data types: Objects and abstract data types both combine functions and data, and abstraction in both cases involves distinguishing between a public interface and private implementation.

  Other features of object-oriented languages, however, make abstraction in object-oriented languages more flexible than abstraction with abstract data types.

$$\frac{a : A \quad f : A \to B}{f(a) : B}$$

Subtyping

$$\frac{a : A \quad A <: B}{a : B}$$

- *Subtyping* is a relation on types that allows values of one type to be used in place of values of another. Specifically, if an object `a` has all the functionality of another object `b`, then we may use `a` in any context expecting `b`.
- The basic principle associated with subtyping is *substitutivity*: If `A` is a subtype of `B`, then any expression of type `A` may be used without type error in any context that requires an expression of type `B`.

- The primary advantage of subtyping is that it permits uniform operations over various types of data.

  For instance, subtyping makes it possible to have heterogeneous data structures that contain objects that belong to different subtypes of some common type.

- Subtyping in an object-oriented language allows functionality to be added without modifying general parts of a system.

Inheritance

- *Inheritance* is the ability to reuse the definition of one kind of object to define another kind of object.
- The importance of inheritance is that it saves the effort of duplicating (or reading duplicated) code and that, when one class is implemented by inheriting from another, changes to one affect the other. This has a significant impact on code maintenance and modification.

Inheritance is not subtyping

Subtyping is a relation on interfaces,

inheritance is a relation on implementations.

One reason subtyping and inheritance are often confused is that some class mechanisms combine the two. A typical example is C++, in which `A` will be recognized by the compiler as a subtype of `B` only if `B` is a public base class of `A`. Combining subtyping and inheritance is an elective design decision.

History of objects

SIMULA and Smalltalk

- Objects were invented in the design of SIMULA and refined in the evolution of Smalltalk.

- SIMULA: The first object-oriented language.

  The object model in SIMULA was based on procedures activation records, with objects originally described as procedures that return a pointer to their own activation record.

- Smalltalk: A dynamically typed object-oriented language.

  Many object-oriented ideas originated or were popularised by the Smalltalk group, which built on Alan Kay's then-futuristic idea of the Dynabook.

Everything is an object.

SIMULA

- Extremely influential as the first language with classes objects, dynamic lookup, subtyping, and inheritance.
- Originally designed for the purpose of *simulation* by O.-J. Dahl and K. Nygaard at the Norwegian Computing Center, Oslo, in the 1960s.
- SIMULA was designed as an extension and modification of Algol 60. The main features added to Algol 60 were: class concepts and reference variables (pointers to objects); pass-by-reference; input-output features; coroutines (a mechanism for writing concurrent programs).

- A generic event-based simulation program

  ```
  Q := make_queue(initial_event);
  repeat
    select event e from Q
    simulate event e
    place all events generated by e on Q
  until Q is empty
  ```

  naturally requires:

  - A data structure that may contain a variety of kinds of events. $\leadsto$ subtyping
  - The selection of the simulation operation according to the kind of event being processed. $\leadsto$ dynamic lookup
  - Ways in which to structure the implementation of related kinds of events. $\leadsto$ inheritance

Objects in SIMULA

Class: A procedure returning a pointer to its activation record.

Object: An activation record produced by call to a class, called an instance of the class. $\rightsquigarrow$ a SIMULA object is a closure

- SIMULA implementations place objects on the heap.
- Objects are deallocated by the garbage collector (which deallocates objects only when they are no longer reachable from the program that created them).

SIMULA

Object-oriented features

- *Objects*: A SIMULA object is an activation record produced by call to a class.
- *Classes*: A SIMULA class is a procedure that returns a pointer to its activation record. The body of a class may initialise the objects it creates.
- *Dynamic lookup*: Operations on an object are selected from the activation record of that object.

- *Abstraction*: Hiding was not provided in SIMULA 67 but was added later and used as the basis for C++.

  SIMULA 67 did not distinguish between public and private members of classes.

  A later version of the language, however, allowed attributes to be made “protected”, which means that they are accessible for subclasses (but not for other classes), or “hidden”, in which case they are not accessible to subclasses either.

- *Subtyping*: Objects are typed according to the classes that create them. Subtyping is determined by class hierarchy.
- *Inheritance*: A SIMULA class may be defined, by class prefixing, as an extension of a class that has already been defined including the ability to redefine parts of a class in a subclass.

SIMULA

Sample code[a]

```
CLASS POINT(X,Y); REAL X, Y;
  COMMENT***CARTESIAN REPRESENTATION
BEGIN
  BOOLEAN PROCEDURE EQUALS(P); REF(POINT) P;
    IF P =/= NONE THEN
      EQUALS := ABS(X-P.X) + ABS(Y-P.Y) < 0.00001;
  REAL PROCEDURE DISTANCE(P); REF(POINT) P;
    IF P == NONE THEN ERROR ELSE
      DISTANCE := SQRT( (X-P.X)**2 + (Y-P.Y)**2 );
END***POINT***
```

[a] See Chapter 4(§1) of *SIMULA begin* (2nd edition) by G. Birtwistle, O.-J. Dahl, B. Myhrhug, and K. Nygaard. Chartwell-Bratt Ltd., 1980.

```
CLASS LINE(A,B,C); REAL A,B,C;
  COMMENT***Ax+By+C=0 REPRESENTATION
BEGIN
  BOOLEAN PROCEDURE PARALLELTO(L); REF(LINE) L;
    IF L =/= NONE THEN
      PARALLELTO := ABS( A*L.B - B*L.A ) < 0.00001;

  REF(POINT) PROCEDURE MEETS(L); REF(LINE) L;
    BEGIN REAL T;
      IF L =/= NONE and ~PARALLELTO(L) THEN
        BEGIN
          ...
          MEETS :- NEW POINT(...,...);
        END;
    END;***MEETS***
```

assignment

pointer assignment

```
  COMMENT*** INITIALISATION CODE
  REAL D;
  D := SQRT( A**2 + B**2 )
  IF D = 0.0 THEN ERROR ELSE
    BEGIN
      D := 1/D;
      A := A*D;  B := B*D;  C := C * D;
    END;
END***LINE***
```

SIMULA

Subclasses and inheritance

SIMULA syntax for a class C1 with subclasses C2 and C3 is

```
CLASS C1
  <DECLARATIONS1>;
C1 CLASS C2
  <DECLARATIONS2>;
C1 CLASS C3
  <DECLARATIONS3>;
```

$C2 <: C1$

$C3 <: C1$

When we create a C2 object, for example, we do this by first creating a C1 object (activation record) and then appending a C2 object (activation record).

Example:

```
POINT CLASS COLOREDPOINT(C); COLOR C;
BEGIN
  BOOLEAN PROCEDURE EQUALS(Q); REF(COLOREDPOINT) Q;
    ...;
END***COLOREDPOINT**

REF(POINT) P;  REF(COLOREDPOINT) CP;
P :- NEW POINT(1.0,2.5);
CP :- NEW COLOREDPOINT(2.5,1.0,RED);
```

NB: SIMULA 67 did not hide fields. Thus,

```
   CP.C := BLUE;
```

changes the color of the point referenced by `CP`.

SIMULA

Object types and subtypes

- All instances of a class are given the same *type*. The name of this type is the same as the name of the class.

- The class names (types of objects) are arranged in a *subtype* hierarchy corresponding exactly to the subclass hierarchy.

Examples:

$B <: A$

$a : REF(A)$

$b : REF(B)$

1.
```
CLASS A;    A CLASS B;

REF(A) a;   REF(B) b;

a :- b; COMMENT***legal since B is
               ***a subclass of A

...

b :- a; COMMENT***also legal, but checked at
               ***run time to make sure that
               ***a points to a B object, so
               ***as to avoid a type error
```

2.
```
inspect a
  when B do b :- a
  otherwise ...
```

3. An error in the original SIMULA type checker surrounding the relationship between subtyping and inheritance:

```
CLASS A;   A CLASS B;
```

SIMULA subclassing produces the subtype relation `B<:A`.

```
REF(A) a;  REF(B) b;
```

SIMULA also uses the semantically incorrect principle that, if `B<:A` then `REF(B)<:REF(A)`.

So: this code . . .

```
PROCEDURE ASSIGNa( REF(A) x )
  BEGIN  x :- a  END;
```
~ a : REF(A)

~ b : REF(B)

```
ASSIGNa(b);
```
type checks

. . . will statically type check, but may cause a type error at run time.

P.S. The same type error occurs in the original implementation of Eiffel. A similar problem occurs in Java's covariant arrays (see later).

but needs a runtime checking.

Smalltalk $\sim\!\sim$ Squeak

- Developed at XEROX PARC in the 1970s.
- Major language that popularised objects; very flexible and powerful.
- The object metaphor was extended and refined.
  - Used some ideas from SIMULA; but it was a completely new language, with new terminology and an original syntax.
  - Abstraction via private *instance variables* (data associated with an object) and public *methods* (code for performing operations).
  - Everything is an object; even a class. All operations are messages to objects.

Smalltalk

Motivating application : Dynabook

- Concept developed by Alan Kay.
- Influence on Smalltalk:
  - Objects and classes as useful organising concepts for building an entire programming environment and system.
  - Language intended to be the operating system interface as well as the programming language for Dynabook.
  - Syntax designed to be used with a special-purpose editor.
  - The implementation emphasised flexibility and ease of use over efficiency.

Smalltalk

Classes and objects

class name	`Point`
super class	`Object`
class var	`pi`
instance var	`x, y`
class messages and methods	
<...names and codes for methods ...>	
instance messages and methods	
<...names and codes for methods ...>	

Definition of `Point` class

A class message and method for point objects

local declarations

```
newX:xvalue Y:yvalue ||
    ^ self new x: xvalue y: yvalue
```

formal parameters

return

A class message and method for point objects

```
newX:xvalue Y:yvalue ||
   ^ self new x: xvalue y: yvalue
```

A new point at coordinates $(3, 4)$ is created when the message

```
newX:3 Y:4
```

actual parameters

is sent to the `Point` class.

For instance:

```
p <- Point newX:3 Y:4
```