

Sequential Composition

Expressions or statements are sequenced using ";". Hence

```
val a = (1+2;3+4);
val a = 7 : int
(x:=1;!x);
val it = 1 : int
```

Iteration

`while expr1 do expr2` implements iteration (and returns `unit`); Thus

```
(while false do 10);
val it = () : unit
while !x > 0 do x:= !x-1;
val it = () : unit
!x;
val it = 0 : int
```

Simple I/O

The function

```
print;
```

```
val it = fn : string -> unit
```

prints a string onto standard output.

For example,

```
print("Hello World\n");
Hello World
```

The conversion routines

```
Real.toString;
```

```
val it = fn : real -> string
```

```
Int.toString;
```

```
val it = fn : int -> string
```

```
Bool.toString;
```

```
val it = fn : bool -> string
```

convert a value (`real`, `int` or `bool`) into a `string`. Unlike Java, the call must be explicit.

For example,

```
print(Int.toString(123));
123
```

Also available are

```
Real.fromString;
```

```
val it = fn : string -> real
option
```

```
Int.fromString;
```

```
val it = fn : string -> int
option
```

```
Bool.fromString;
```

```
val it = fn : string -> bool
option
```

which convert from a `string` to a `real` or `int` or `bool` *if possible*. (That's why the `option` type is used).

For example,

```
case (Int.fromString("123"))
of
```

```
    SOME(i) => i | NONE => 0;
```

```
val it = 123 : int
```

```
case (Int.fromString(
    "One two three")) of
```

```
    SOME(i) => i | NONE => 0;
```

```
val it = 0 : int
```

Text I/O

The structure `TextIO` contains a wide variety of I/O types, values and functions. You load these by entering:

```
open TextIO;
```

Among the values loaded are

- `type instream`
This is the type that represents input text files.
- `type ostream`
This is the type that represents output text files.
- `type vector = string`
Makes `vector` a synonym for `string`.
- `type elem = char`
Makes `elem` a synonym for `char`.

- `val stdIn : instream`
`val stdOut : ostream`
`val stderr : ostream`
Predefined input and output streams.
- `val openIn :`
`string -> instream`
`val openOut :`
`string -> ostream`
Open an input or output stream. For example,
`val out =`
`openOut("/tmp/test1");`
`val out = - : ostream`
- `val input :`
`istream -> vector`
Read a line of input into a `string` (`vector` is defined as equivalent to `string`). For example (user input is in red):

- ```
val s = input(stdIn);
Hello!
val s = "Hello!\n" : vector
```
- `val inputN :`  
`istream * int -> vector`  
Read the next `n` input characters into a `string`. For example,  
`val t = inputN(stdIn,3);`  
`abcde`  
`val t = "abc" : vector`
  - `val inputAll :`  
`istream -> vector`  
Read the rest of the input file into a `string` (with newlines separating lines). For example,  
`val u = inputAll(stdIn);`  
`Four score and`  
`seven years ago ...`  
`val u = "Four score and\nseven`  
`years ago ...\n" : vector`

- `val endOfStream :`  
`istream -> bool`  
Are we at the end of this input stream?
- `val output :`  
`ostream * vector -> unit`  
Output a `string` on the specified output stream. For example,  
`output(stdOut,`  
`"That's all folks!\n");`  
`That's all folks!`

## String Operations

ML provides a wide variety of string manipulation routines. Included are:

- The string concatenation operator, ^  
`"abc" ^ "def" = "abcdef"`
- The standard 6 relational operators:  
`< > <= >= = <>`
- The string size operator:  
`val size : string -> int`  
`size ("abcd");`  
`val it = 4 : int`
- The string subscripting operator (indexing from 0):  
`val sub =`  
`fn : string * int -> char`  
`sub("abcde",2);`  
`val it = #"c" : char`

- The substring function  
`val substring :`  
`string * int * int -> string`  
This function is called as  
`substring(string,start,len)`  
`start` is the starting position, counting from 0.  
`len` is the length of the desired substring. For example,  
`substring("abcdefghij",3,4)`  
`val it = "defg" : string`
- Concatenation of a list of strings into a single string:  
`concat :`  
`string list -> string`  
For example,  
`concat ["What's"," up","?"];`  
`val it = "What's up?" : string`

- Convert a character into a string:  
`str : char -> string`  
For example,  
`str("#x");`  
`val it = "x" : string`
- "Explode" a string into a list of characters:  
`explode : string -> char list`  
For example,  
`explode("abcde");`  
`val it =`  
`["#a",#"b",#"c",#"d",#"e"] :`  
`char list`
- "Implode" a list of characters into a string.  
`implode : char list -> string`  
For example,  
`implode`  
`["#a",#"b",#"c",#"d",#"e"];`  
`val it = "abcde" : string`

## Structures and Signatures

In C++ and Java you can group variable and function definitions into classes. In Java you can also group classes into packages.

In ML you can group value, exception and function definitions into *structures*.

You can then import selected definitions from the structure (using the notation `structure.name`) or you can `open` the structure, thereby importing all the definitions within the structure.

(Examples used in this section may be found at

`~cs538-1/public/sml/struct.sml`)

The general form of a structure definition is

```
structure name =
struct
 val, exception and
 fun definitions
end
```

For example,

```
structure Mapping =
struct
 exception NotFound;
 val create = [];
 fun lookup(key,[]) =
 raise NotFound
 | lookup(key,
 (key1,value1)::rest) =
 if key = key1
 then value1
 else lookup(key,rest);
end
```

```
fun insert(key,value,[]) =
 [(key,value)]
| insert(key,value,
 (key1,value1)::rest) =
 if key = key1
 then (key,value)::rest
 else (key1,value1)::
 insert(key,value,rest);
end;
```

We can access members of this structure as `Mapping.name`. Thus

```
Mapping.insert(538,"languages",[]);
val it = [(538,"languages")] :
(int * string) list
open Mapping;
exception NotFound
val create : 'a list
val insert : 'a * 'b * ('a * 'b)
 list -> ('a * 'b) list
val lookup : 'a * ('a * 'b)
 list -> 'b
```

## Signatures

Each structure has a *signature*, which is its type.

For example, `Mapping`'s signature is

```
signature Mapping :
sig
 exception NotFound
 val create : 'a list
 val insert : 'a * 'b *
 ('a * 'b) list ->
 ('a * 'b) list
 val lookup : 'a *
 ('a * 'b) list -> 'b
end
```

You can define a signature as

```
signature name = sig
 type definitions for values,
 functions and exceptions
end
```

For example,

```
signature Str2IntMapping =
sig
 exception NotFound;
 val lookup:
 string * (string*int) list
 -> int;
end;
```

Signatures can be used to

- Restrict the type of a value or function in a structure.
- Hide selected definitions that appear in a structure

For example

```
structure Str2IntMap :
 Str2IntMapping = Mapping;
defines a new structure, Str2IntMap,
created by restricting Mapping to the
Str2IntMapping signature. When
we do this we get
```

```
open Str2IntMap;
exception NotFound
val lookup : string *
 (string * int) list -> int
```

Only **lookup** and **NotFound** are  
created, and **lookup** is limited to keys  
that are strings.

## Extending ML's Polymorphism

In languages like C++ and Java we  
must use types like **void\*** or **Object**  
to simulate the polymorphism that  
ML provides. In ML whenever possible  
a general type (a polytype) is used  
rather than a fixed type. Thus in

```
fun len([]) = 0
 | len(a::b) = 1 + len(b);
```

we get a type of

```
'a list -> int
```

because this is the most general type  
possible that is consistent with **len**'s  
definition.

Is this form of polymorphism general  
enough to capture the general idea of  
making program definitions as type-  
independent as possible?

It isn't, and to see why consider the  
following ML definition of a merge  
sort. A merge sort operates by first  
splitting a list into two equal length  
sublists. The following function does  
this:

```
fun split [] = ([],[])
 | split [a] = ([a],[])
 | split (a::b::rest) =
 let val (left,right) =
 split(rest) in
 (a::left, b::right)
 end;
```

After the input list is split into two  
halves, each half is recursively sorted,  
then the sorted halves are merged  
together into a single list.

The following ML function merges  
two sorted lists into one:

```
fun merge([],[]) = []
 | merge([],hd::tl) = hd::tl
 | merge(hd::tl,[],) = hd::tl
 | merge(hd::tl,h::t) =
 if hd <= h
 then hd::merge(tl,h::t)
 else h::merge(hd::tl,t)
```

With these two subroutines, a  
definition of a sort is easy:

```
fun sort [] = []
 | sort([a]) = [a]
 | sort(a::b::rest) =
 let val (left,right) =
 split(a::b::rest) in
 merge(sort(left),
 sort(right))
 end;
```

This definition looks very general—it should work for a list of any type.

Unfortunately, when ML types the functions we get a surprise:

```
val split = fn : 'a list ->
 'a list * 'a list
val merge = fn : int list *
 int list -> int list
val sort = fn :
 int list -> int list
```

`split` is polymorphic, but `merge` and `sort` are limited to integer lists!

Where did this restriction come from?

The problem is that we did a comparison in `merge` using the `<=` operator, and ML typed this as an integer comparison.

We can make our definition of `sort` more general by adding a comparison function, `le(a,b)` as a parameter to `merge` and `sort`. If we curry this parameter we may be able to hide it from end users. Our updated definitions are:

```
fun merge(le, [], []) = []
 | merge(le, [], hd::tl) = hd::tl
 | merge(le, hd::tl, []) = hd::tl
 | merge(le, hd::tl, h::t) =
 if le(hd, h)
 then hd::merge(le, tl, h::t)
 else h::merge(le, hd::tl, t)
```

```
fun sort le [] = []
 | sort le [a] = [a]
 | sort le (a::b::rest) =
 let val (left, right) =
 split(a::b::rest) in
 merge(le, sort le left,
 sort le right)
 end;
```

Now the types of `merge` and `sort` are:

```
val merge = fn :
 ('a * 'a -> bool) *
 'a list * 'a list -> 'a list
val sort = fn : ('a * 'a -> bool)
 -> 'a list -> 'a list
```

We can now “customize” `sort` by choosing a particular definition for the `le` parameter:

```
fun le(a,b) = a <= b;
val le = fn : int * int -> bool
```

```
fun intsort L = sort le L;
val intsort =
 fn : int list -> int list
intsort(
 [4,9,0,2,111,~22,8,~123]);
val it = [~123,~22,0,2,4,8,9,111]
: int list
fun strle(a:string,b) =
 a <= b;
val strle =
 fn : string * string -> bool
fun strsort L = sort strle L;
val strsort =
 fn : string list -> string list
strsort(
 ["aac","aaa","ABC","123"]);
val it =
 ["123","ABC","aaa","aac"] :
 string list
```