Moscow ML implements the Core language of Standard ML (SML), as defined in the 1997 Definition of Standard ML, and supports most required parts of the new SML Basis Library. Moscow ML also provides a simple subset of the Standard ML Modules language, restricted to signatures and non-nested structures. It supports separate compilation and the generation of stand-alone executables.

This document explains how to use the Moscow ML system. A companion document, the Moscow ML Language Overview, summarizes Moscow ML syntax and some built-in functions [7]. For a list of textbooks and other materials on Standard ML programming, see Section 16 below.

Acknowledgements: The Caml Light system was instrumental in creating Moscow ML, which uses its runtime system and essentially the same bytecode generator. Many other aspects of the design were derived from Caml Light, developed by Xavier Leroy and Damien Doligez at INRIA, France [3, 4]. The ML Kit helped solving problems of parsing, infix resolution, and type inference [1].

The Moscow ML home page is http://www.dina.kvl.dk/~sestoft/mosml.html

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1 Getting started

1.1 Installation

Get a copy of the Moscow ML system executables (see Section 15 for instructions) and unpack them in your home directory (under Unix) or in directory C:\ (under MS Windows and DOS). This creates a directory mosml. Read the file mosml/install.txt. This manual, and the Moscow ML Language Overview, are in directory mosml/doc.

1.2 The interactive system

The interactive system is invoked by typing mosml at the shell prompt. It allows you to enter declarations and evaluate expressions:

```
$ mosml
Moscow ML version 1.43 (April 1998)
Enter 'quit();' to quit.
- fun fac n = if n = 0 then 1 else n * fac (n-1);
  > val fac = fn : int -> int
  - fac 10;
  > val it = 3628800 : int
```

You can quit the interactive session by typing 'quit();' or control-D (under Unix) or control-Z followed by newline (under MS Windows and DOS). Type help "lib"; for an overview of built-in function libraries, and e.g. help "Array" for help on Array operations. See Section 3 for further information on mosml.

1.3 The batch compiler and linker

The batch compiler and linker is invoked by typing mosmlc at the shell prompt. It can compile ML source files separately (mosmlc -c) and link them to obtain executables (mosmlc -o), in a manner similar to C compilers. See Section 5 for further information on mosmlc.

1.4 A simple module system

Moscow ML provides a simple subset of the Standard ML Modules language, restricted to signatures and non-nested structures. A Moscow ML program consists of one or more units. A unit U has a signature (or interface) in file U.sig and a body (or implementation) in file U.sml. The unit signature corresponds to a Standard ML signature, and the unit body corresponds to a Standard ML structure. Moscow ML supports type-safe separate compilation and linking. Section 4 gives the syntax and an informal semantics of compilation units. Section 6 explains automatic recompilation management.

1.5 What is new in release 1.43

- Weak pointers and arrays of weak pointers (structure Weak); see Section 8.
- The load paths can be set from the interactive system, and the system's prompts and responses can be turned off (option --quietdec, variable Meta.quietdec). This facilitates writing scripts with mosml.
- Prettyprinters can be installed also on base types and abstract types.
- The Help facility can be adapted to other uses.
- Mosmllex now supports abbreviations for regular expressions (thanks to Ken Larsen).
- Added dynamic linking of external functions (structure Dynlib) under Linux, Solaris and OSF/1 (thanks to Ken Larsen). See Section 9.
- Access to GNU gdbm persistent hash tables (structures Gdbm, Polygdbm); see Section 10. Requires Dynlib.
- For other minor changes and fixes, see file mosml/doc/releases.txt.
2 Core language and libraries

Moscow ML implements the Core language of Standard ML as revised in 1997 [6, 5], and much of the
Standard ML Basis Library [2], the most important omission being the functional stream input-output
operations. The second edition of Paulson’s textbook *ML for the Working Programmer* uses the revised
Core language and the new SML Basis Library.

2.1 The Standard ML Basis Library

The Standard ML Basis Library is a joint effort of the Standard ML of New Jersey, MLWorks, and
Moscow ML developers\(^1\) to enhance the portability of Standard ML programs.

The *Moscow ML Language Overview* [7] lists the library structures implemented by Moscow ML, and
contains an index to all the identifiers they define. The same information is available also from mosml’s
on-line help (Section 3.1) and as hypertext from Moscow ML’s homepage.

For a comprehensive description of the libraries, see the Basis Library documentation [2], which will
become available from a commercial publisher. Currently it must be obtained from the Internet; see
Section 16.

The Basis Library and the revised Standard ML language are slightly incompatible with both the
1990 Definition of Standard ML and with SML/NJ version 0.93. Invoking Moscow ML with `mosml -P
sml90’ gives a top-level environment compatible with the 1990 Definition. Invoking Moscow ML with
option `mosml -P nj93’, gives a top-level environment compatible with the old SML/NJ version 0.93.
See Section 3.3 for more information on command-line options. An important change in SML 1997 is the
adoption of value polymorphism; see Section 7.

3 The interactive system

The interactive system mosml is invoked simply by typing mosml at the command line:

```
$ mosml
Moscow ML version 1.43 (April 1998)
Enter ‘quit()’; to quit.
```

The interactive system can be terminated by typing `quit();` and newline, or control-D (under Unix) or
control-Z and newline (under MS Windows and DOS). Type `help "";` for help on built-in functions.

Invoking the interactive system with command line arguments

```
mosml file1; ...; fileN
```

is equivalent to invoking mosml and, when Moscow ML has started, entering

```
(use "file1"; ...; use "fileN";)
```

3.1 On-line help

In a mosml session, you may type `help "lib";` for an overview of built-in function libraries. To get help
on a particular identifier, such as fromString, type

```
help "fromstring";
```

This will produce a menu of all library structures which contain the identifier fromString (disregarding
the lowercase/uppercase distinction):

\(^1\) The Basis Library authors are Andrew Appel (Princeton, USA); Emden Gansner (AT&T Research, USA); John Reppy,
Lal George, Lorenz Haehlbergen, Dave MacQueen (Bell Laboratories, USA); Matthew Arcus, Dave Berry, Richard Brooksby,
Nick Barnes, Brian Monahan, Jon Thackray (Harlequin Ltd., Cambridge, England); Carsten Müller (Berlin, Germany);
and Peter Sestoft (Royal Veterinary and Agricultural University, Denmark).
Choosing a number from this menu will invoke the help browser on the desired structure, e.g. Int. The help browser is primitive but easy to use. It works best with a window size of 24 lines.

The texts accessed by help are found in directory mosml/lib. For instance, all List functions are described in file mosml/lib/List.sig.

3.2 Editing and running ML programs

Unix and Emacs You may run mosml as a subshell under Emacs. You should use the mosml version of the SML mode for Emacs; see file mosml/utility/emacs for instructions. In case of errors, Emacs can interpret mosml’s error messages and jump to the offending piece of source code. This is very convenient.

Window systems In a window-oriented system, such as MacOS, MS Windows, or the X window system, you may run mosml in one window and edit source code in another. After (re-)editing the source file, you must issue a use command in the mosml window.

MS DOS You may use the simple edit script to invoke an editor from inside a mosml session; see file mosml/utility/dosedit for instructions. You will not need to quit the mosml session to edit a source file, and the script will automatically reload the newly edited file.

3.3 Command-line options

-1 directory Specifies directories to be searched for interface files, bytecode files, and source files. A call to use, load or loadOne will first search the current directory, then all directories specified by option ‘-1’ in order of appearance from left to right, and finally the standard library directory. (This option affects the variable Meta.loadPath; see Section 3.4).

-valuepoly Specifies that the type checker should use ‘value polymorphism’; see Section 7. Default.

-imtypes Specifies that the type checker should distinguish between imperative and applicative type variables, generalize all applicative type variables, and generalize imperative type variables only in non-expansive expressions. See Section 7.

-quietdec Turns off the interactive system’s prompt and responses, except for the two-line start-up message, warnings, and error messages. Useful for writing scripts in SML. Sets Meta.quietdec to true; see Section 3.4.

-P unit-set Determines which library units will be included and open at compile-time. Any library unit in the load path can be used by the compile function for type checking purposes. Thus regardless of the -P option, the compile function knows the type of library functions such as Array.foldl.

-P default This provides an initial environment for the new Basis Library. The units Array, Char, List, String, and Vector will be loaded, and units Char, List, and String will be partially opened. This is the default.
The following non-standard primitives are defined in unit `stdlib`. Non-standard primitives in the interactive system. Hence these primitives cannot be used from source files which are compiled separately.

\[ \text{compile : string -> unit} \]

Evaluating `compile "U.sigt"` will compile and elaborate the unit signature in file `U.sigt`, producing a compiled signature file `U.ui`. During compilation, the compiled signatures of other units will be accessed if they are mentioned in `U.sigt`.

Evaluating `compile "U.sml"` will elaborate and compile the unit body in file `U.sml`, producing a bytecode file `U.uo`. If there is an explicit signature `U.sigt`, then file `U.ui` must exist, and the unit body must match the signature. If there is no `U.sigt`, then an inferred signature file `U.ui` will be produced also. No evaluation takes place. During compilation, the compiled signatures of other units will be accessed if they are mentioned in `U.sml`.

The declared identifiers will be reported if `verbose` is `true` (see below); otherwise compilation will be silent. In any case, compilation warnings are reported, and compilation errors abort the compilation and raise the exception `Fail` with a string argument.

\[ \text{exnName : exn -> string} \]

Returns a name for the exception constructor in the exception. Never raises an exception itself. The name returned may be that of any exception constructor aliasing with `exn`. For instance, `let exception E1; exception E2 = E1 in exnName E2 end` may evaluate to "E1" or "E2".

\[ \text{exnMessage : exn -> string} \]

Formats and returns a message corresponding to the exception. For the exceptions defined in the SML Basis Library, the message will include the argument carried by the exception.

\[ \text{installPP : (ppstream -> 'a -> unit) -> unit} \]

Evaluating `installPP pp` installs the prettyprinter `pp` at type `ty`, provided `pp` has type `ppstream -> ty -> unit`. The type `ty` must be a nullary (parameter-less) type constructor, either built-in (such as `int` or `bool`) or user-defined. Whenever a value of type `ty` is about to be printed by the interactive system, and whenever function `printVal` is invoked on an argument of type `ty`, the prettyprinter `pp` will be invoked to print it. See the example in `mosml/examples/prettty`.

Additional library units can be loaded into the interactive system by using the `load` function; see Section 3.4 below.

\[ \text{stdlib stdlib-directory} \]

Specify the standard library directory to be `stdlib-directory`. The default standard library is usually `~/.sml/lib` under Unix and `c:\mosml\lib` under MS Windows and DOS.

3.4 Non-standard primitives in the interactive system

The following non-standard primitives are defined in unit `meta`, loaded (and open by default) only in the interactive system. Hence these primitives cannot be used from source files which are compiled separately.

The functions `compile` and `load` deal with Moscow ML compilation units; see Section 4.
load : string -> unit
Evaluating load "U" will load and evaluate the compiled unit body from file U.uo. The resulting values are not reported, but exceptions are reported, and cause evaluation and loading to stop. If U is already loaded, then load "U" has no effect. If any other unit is mentioned by U but not yet loaded, then it will be loaded automatically before U. The loaded unit(s) must be in the current directory or in a directory on the loadPath list (see below).

After loading a unit, it can be opened with open U. Opening it at top-level will list the identifiers declared in the unit.

When loading U, it is checked that the signatures of units mentioned by U agree with the signatures used when compiling U, and it is checked that the signature of U has not been modified since U was compiled; these checks are necessary for type safety. The exception Fail is raised if the signature checks fail, or if the file containing U or a unit mentioned by U is not found.

loadOne : string -> unit
Evaluating loadOne "U" is similar to load "U", but raises exception Fail if U is already loaded or if some unit mentioned by U is not yet loaded. That is, it does not automatically load any units mentioned by U. It performs the same signature checks as load.

loadPath : string list ref
This variable determines the load path: which directories will be searched for interface files (.ui files), bytecode files (.uo files), and source files (.sml files). This variable affects the load, loadOne, and use functions. The current directory is always searched first, followed by the directories in loadPath, in order. By default, only the standard library directory is in the list, but if additional directories are specified using option -I, then these directories are prepended to Meta.loadPath.

printVal : 'a -> 'a
This is a polymorphic function provided as a quick debugging aid. It is an identity function, which as a side-effect prints its argument to standard output exactly as it would be printed at top-level. Output is flushed immediately. For printing strings, the function print is probably more useful than printVal.

printDepth : int ref
This variable determines the depth (in terms of nested constructors, records, tuples, lists, and vectors) to which values are printed by the top-level value printer and the function printVal. The components of the value whose depth is greater than printDepth are printed as '#'. The initial value of printDepth is 20.

printLength : int ref
This variable determines the way in which list values are printed by the top-level value printer and the function printVal. If the length of a list is greater than printLength, only the first printLength elements are printed, and the remaining elements are printed as '...'. The initial value of printLength is 200.

quietdec : bool ref
This variable, when true, turns off the interactive system's prompt and responses, except warnings and error messages. Useful for writing scripts in SML. The default value is false; it can be set to true with the -quietdec command line option; see Section 3.3.

quit : unit -> unit
Evaluating quit() quits Moscow ML immediately.

quotation : bool ref
Determines whether quotations and antiquotations are permitted in declarations entered at top-level and in files compiled with compile; see Section 11. When quotation is false (the default), the backquote character is an ordinary symbol which can be used in ML symbolic identifiers. When quotation is true, the backquote character is illegal in symbolic identifiers, and a quotation "a b c" will be evaluated to an object of type 'a frag list.

system : string -> int
Evaluating system "com" causes the command com to be executed by the operating system. If a non-zero integer is returned, this must indicate that the operating system has failed to execute the command. Under MS DOS, the integer returned always equals 0.
use : string -> unit

Evaluating use "f" causes ML declarations to be read from file f as if they were entered from the console. The file must be in the current directory or in a directory on the loadPath list. A file loaded by use may, in turn, evaluate calls to use. For best results, use use only at top level, or at top level within a used file.

valuepoly : bool ref

Determines whether the type checker should use `value polymorphism`; see Section 7. Command-line option -valuepoly sets valuepoly to true (the default), whereas option -imptypes sets valuepoly to false; see Sections 3.3 and 5.2.

verbose : bool ref

Determines whether the signature inferred by a call to compile will be printed. The printed signature follows the syntax of Moscowl ML signatures, so the output of compile "U.sml" can be edited to subsequently create file U.sig. The default value is false.

4 Modules and compilation units

4.1 Basic concepts

A Moscowl ML program can consist of one or more compilation units, or units for short. A compilation unit consists of an optional unit signature and a unit body. The unit signature specifies the contents of the unit; it is an interface to the unit. The unit body declares the contents of the unit; it provides an implementation of the unit. The following analogies may be helpful:

<table>
<thead>
<tr>
<th>Moscowl ML</th>
<th>unit signature</th>
<th>unit body</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard ML</td>
<td>signature</td>
<td>structure</td>
</tr>
<tr>
<td>Caml Light</td>
<td>module interface</td>
<td>module implementation</td>
</tr>
<tr>
<td>Modula-2</td>
<td>interface module</td>
<td>implementation module</td>
</tr>
</tbody>
</table>

The unit body is always present, whereas the signature can be omitted. When the unit signature is present, it is called the explicit signature to distinguish it from the signature inferred when elaborating the unit body. When present, the explicit signature must be matched by the body, and only those identifiers specified in the signature are visible outside the unit. If no signature is given, all identifiers visible at the end of the unit body are visible outside the unit.

Units are closely associated with files, as in Modula-2. The body of the unit called 'U' is defined in a file called 'U.sml', and its explicit signature (if any) in file 'U.sig'.

<table>
<thead>
<tr>
<th>Files containing program text:</th>
<th>Files created by the compiler:</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.sig unit signature, specifications</td>
<td>U.ui compiled unit signature</td>
</tr>
<tr>
<td>U.sml unit body, declarations</td>
<td>U.no compiled unit body, bytecode</td>
</tr>
</tbody>
</table>

4.2 Units without explicit signature

A unit U without an explicit signature consists of a file U.sml containing

structure U = struct ... declarations ... end

This is the same as a simple SML structure declaration. There must be no corresponding explicit signature file U.sig.

4.3 Units with explicit signature

A unit U with an explicit signature consists of a signature file U.sig containing

signature U = sig ... specifications ... end

and a file U.sml, containing
structure U :> U = struct ... declarations ... end

This is the same as a SML structure declaration with an opaque signature constraint. Note that the file name, signature name, and structure name must be the same. The notation 'U :> U' is an opaque signature constraint, meaning that other units have no access to the internals of U.sml, only to the signature U.sig.

To illustrate the difference between transparent and opaque signature constraints, consider the Standard ML (not Moscow ML) declarations:

```plaintext
signature SIG = sig
  type t
  val x: t
end;

structure S: SIG = struct
  type t = int
  val x = 17
end;
```

Given these declarations, the expression S.x+3 will typecheck. Although the signature SIG just says that there exists a type t, constraining S with SIG does not hide the fact that S.x is actually an integer.

On the other hand, an opaque signature constraint, as in Moscow ML units, does hide the true nature of t and x:

```plaintext
structure M :> SIG = struct
  type t = int
  val x = 17
end;
```

After this declaration, M.x+3 would fail to typecheck: the type checker cannot see that M.t is int and M.x is an integer. Often such hiding is just what is needed for software engineering purposes.

### 4.4 Syntax of unit signatures

Moscow ML unit signatures are very similar to Standard ML signatures as defined in [6]; the differences are explained below. A unit signature (in file U.sig) has the form:

```plaintext
unitsig ::= signature unitid = sig uspec end
            named signature
            signature (old syntax)

uspec ::= val valdesc
type tydesc
type tybind
eqtype tydesc
datatype datbind
datatype datbind withtype tybind
exception excdesc
local lspec in uspec end
uspec | lspec sequential

lspec ::= open unitid_1 ... unitid_n open other units
type tybind
type abbreviation
local lspec in lspec end local specifications
empty
lspec | lspec sequential
```

Note:

1. Type abbreviations `type tybind` are permitted in signatures.
2. There are no structure specifications and no sharing specifications.
3. No type, value, or exception may be specified twice at top-level.
4. A `local` specification can be used only to restrict the scope of `open` specifications and type abbreviations.
5. An open specification can appear only inside local.
6. The 'signature unitid = sig' and 'end' parts may be left out, although this is not recommended.

Restriction (2) is the most significant one. Restriction (3), and restrictions similar to (4) and (5), are imposed by the Standard ML of New Jersey implementation also.

4.5 Syntax of unit bodies

A unit body (in file U.sml) has the form:

```
unitbody ::= structure unitid = struct dec end
           | structure unitid :> unitid = struct dec end
           | structure with signature dec
```

A long identifier can refer to entities declared in other units. In Moscow ML, the syntax of long identifiers is:

```
longid ::= id            identifier
         | unitid&id   qualified identifier
```

where unitid and id are arbitrary SML identifiers (either symbolic or alphanumeric).

A qualified identifier unitid&id denotes an entity id declared in the compilation unit unitid. A qualified identifier can denote either a value variable, a value constructor, an exception constructor, or a type constructor. As in Standard ML, a longid appearing in a defining position, such as a value variable in a pattern, cannot have a qualifier: the identifier being defined will always belong to the current unit.

An open declaration has the form

```
open U_1 ... U_n
```

where U_1 ... U_n are names of units. The units are opened from left to right, in the order U_1 ... U_n. The text following an open U declaration can reference identifiers declared in U without explicitly specifying the name of the unit, subject to the usual scope rules of Standard ML. That is, one can use id instead of U.id.

In the interactive system, a unit must be loaded before it can be opened. In the batch compilation system, the linker links in (only) the needed declarations from opened units.

A unit body U.sml must elaborate to a structure S. If there is an explicit signature U.sig corresponding to U.sml, then the resulting structure must match the explicit signature. As in Standard ML (but in contrast to Caml Light), no reference is made to the signature while elaborating the unit body.

4.6 An example program consisting of three units

To illustrate the module system, we present a tiny program working with arithmetic expressions. It consists of three units Expr, Reduce, and Evaluate. This example is in mosml/examples/manual.

File Expr.sml below contains structure Expr, which defines a datatype expr for representing expressions and a function show to display them. It has no signature constraint and therefore exports both the datatype and the function:

```
structure Expr = struct
datatype expr = Cst of int | Neg of expr | Plus of expr * expr

fun show (Cst n) = makestring n
   | show (Neg e) = "(-" ^ show e ^ ")"
   | show (Plus (e1, e2)) = "(" ^ show e1 ^ "+" ^ show e2 ^ ")"
end
```

File Reduce.sig below contains the signature Reduce, which specifies a function for reducing expressions. It mentions the type Expr.expr from Expr:
signature Reduce = sig
  val reduce : Expr.expr -> Expr.expr
end

File Reduce.sml below contains the structure Reduce, which has a signature constraint, and therefore exports only the function reduce specified in the signature:

structure Reduce :> Reduce = struct
  local open Expr
  in
    fun negate (Neg e) = e
    | negate e = Neg e
    fun reduce (Neg (Neg e)) = e
    | reduce (Neg e) = negate (reduce e)
    | reduce (Plus (Cst 0, e2)) = reduce e2
    | reduce (Plus (e1, Cst 0)) = reduce e1
    | reduce (Plus (e1, e2)) = Plus (reduce e1, reduce e2)
   | reduce e = e
  end
end

File Evaluate.sig below contains the signature Evaluate, which specifies a function eval for evaluating expressions, and a function test. Note the use of 'open Expr' to make the type expr refer to Expr.expr:

signature Evaluate = sig
  local open Expr
  in
    val eval : expr -> int
    val test : expr -> bool
  end
end

File Evaluate.sml below contains structure Evaluate, which has a signature constraint, and mentions unit Expr as well as Reduce:

structure Evaluate :> Evaluate = struct
  local open Expr
  in
    fun eval (Cst n) = n
    | eval (Neg e) = ~ (eval e)
    | eval (Plus (e1, e2)) = eval e1 + eval e2;
    fun test e = (eval e = eval (Reduce.reduce e))
  end
end

4.7 Compiling, linking, and loading units

Units can be compiled and linked using the batch compiler mosmlc; see Section 5. Units compiled with option -c can be linked together. Use mosml -o mosmlout A.uo to produce a linked executable bytecode file mosmlout which will invoke the runtime system camlrunm. Use mosml -noheader -o mosmlout A.uo to produce a linked bytecode file which can be executed by camlrunm mosmlout. The linker will automatically link any required bytecode files into mosmlout. See Section 5.2 for more options.

Units can also be compiled from and loaded into the interactive system mosml using the primitives compile and load; see Section 3.4 above.

4.8 Organizing programs for compatibility with SML Modules

Moscow ML and Standard ML of New Jersey (version 110) implement the same core language, and many of the same libraries. Here we give advice on organizing structures and signatures so that they can be compiled by both systems.
Assume we have a software system consisting of three structures A, B, and C, where A and B each have a signature constraint, but C does not. Assume further that C depends on A and B. (There must be no functors or nested structures in A and B). We organize them in five files:

<table>
<thead>
<tr>
<th>Source file</th>
<th>File contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.sig</td>
<td>signature A = sig ... end</td>
</tr>
<tr>
<td>B.sig</td>
<td>signature B = sig ... end</td>
</tr>
<tr>
<td>A.sml</td>
<td>structure A =&gt; A = struct ... end</td>
</tr>
<tr>
<td>B.sml</td>
<td>structure B =&gt; B = struct ... end</td>
</tr>
<tr>
<td>C.sml</td>
<td>structure C = struct ... A.foo ... B.bar ... end</td>
</tr>
</tbody>
</table>

Now we can compile these files using `mosmlc` and load them into a `mosml` session as follows (where `$` is the shell prompt and `-'` is the ML prompt):

```
$ mosmlc -c A.sig B.sig A.sml B.sml C.sml
$ mosml
    load "C";
```

Or, we can load and compile them in an SML/NJ session as follows:

```
$ sml
    app use ["A.sig", "B.sig", "A.sml", "B.sml", "C.sml"];
```

Hence the same source files can be used unmodified in both systems.

Note that in Moscow ML, `mosmlc` will create bytecode files A.ui, A.no, and so on. The `load` function does not perform any compilation and hence is very fast. If the source files do not change, there is no need to recompile them with `mosmlc`, which may save much time.

If the source files do change, and have to be recompiled at every use, it may be more practical to use the function `compile`:

```
$ mosml
    app compile ["A.sig", "B.sig", "A.sml", "B.sml", "C.sml"];
    load "C";
```

### 4.9 Matching a unit body against a signature

A unit body S matches a signature SIG under the conditions described in the Definition of Standard ML [6]. Roughly, this means:

- a value specification `val v:t` must be matched by a value variable or value constructor or exception constructor `v` in S whose type generalizes `t`
- a type abbreviation `type t = ty` must be matched by the same type abbreviation `t = ty` in S
- an abstract type `t` must be matched by some type `t` in S
- an abstract equality type `t` must be matched by a type `t` in S admitting equality
- a datatype must be matched by precisely the same datatype in S
- an exception constructor `E` of type `t` must be matched by an exception constructor `E` in S whose type generalizes `t`

Moreover, to facilitate separate compilation, there are some representation constraints:

1. If the specified argument type of a value constructor (in a datatype specification) is an explicit tuple or record, then the declared argument type must be an explicit tuple or record also, and vice versa. This restriction does not apply if there is only one constructor in the datatype.
2. The order of value constructors in a datatype specification must be the same as in the matching datatype declaration.
5 The batch compiler

Moscow ML includes a batch compiler `mosmlc` in addition to the interactive system `mosml`. It compiles and links programs non-interactively, and can turn them into standalone executable files. The batch compiler can be invoked from a Makefile, which simplifies the (re)compilation of large programs considerably; see Section 6.

5.1 Overview

The `mosmlc` command has a command-line interface similar to that of most C compilers. It accepts several types of arguments: source files for unit bodies, source files for unit signatures, and compiled unit bodies.

- An argument ending in `.sig` is taken to be the name of a source file containing a unit signature. Given a file `U.sig`, the compiler produces a compiled signature in the file `U.ui`.
- An argument ending in `.sml` is taken to be the name of a source file containing a unit body. Given a file `U.sml`, the compiler produces compiled object code in the file `U.uo`. It also produces an inferred signature file `U.ui` if there is no explicit signature `U.sig`.
- An argument ending in `.uo` is taken to be the name of a compiled unit body. Such files are linked together, along with the compiled unit bodies obtained by compiling `.sml` arguments (if any), and the necessary Moscow ML library files, to produce a standalone executable program.

The linker automatically includes any additional bytecode files required by the files specified on the command line; option `-i` makes it report all the files that were linked. The linker issues a warning if a file `B` is required by a file `A` that precedes `B` in the command line. At run-time, the top-level declarations of the files are evaluated in the order in which the files were linked; in the absence of any warning, this is the order of the files on the command line.

The output of the linking phase is a file containing compiled code that can be executed by the runtime system `camlrunm`. If `mosmlout` is the name of the file produced by the linking phase, the command

```
camlrunm mosmlout arg1 arg2 ... argn
```

executes the compiled code contained in `mosmlout`. The list of arguments can be obtained in Moscow ML by evaluating the expression `CommandLine('arguments')`.

**MS Windows and DOS:** If the output file produced by the linking phase has extension `.exe`, and option `-noheader` is not used, then the file is directly executable. Hence, an output file named `mosmlout.exe` can be executed with the command

```
mosmlout arg1 arg2 ... argn
```

The output file `mosmlout.exe` consists of a tiny executable file prepended to a linked bytecode file. The executable invokes the `camlrunm` runtime system to interpret the bytecode. As a consequence, this is not a standalone executable: it still requires `camlrunm.exe` to reside in one of the directories in the path.

**Unix:** The output file produced by the linking phase is directly executable (unless the `-noheader` option is used). It automatically invokes the `camlrunm` runtime system, either using a tiny executable prepended to the linked bytecode file, or using the Unix incantation `#/usr/local/bin/camlrunm` or similar. In the former case, `camlrunm` must be in one of the directories in the path; in the latter case it must be in `/usr/local/bin`. To create a true stand-alone executable you may simply concatenate the runtime system with the bytecode file produced by `mosmlc -noheader`, but this adds 60-150 KB to the size of the executable, depending on your version of Unix:

```
cat /usr/local/bin/camlrunm mosmlout > mosmlbin
chmod +x mosmlbin
```
5.2 Command-line options

The following command-line options are recognized by moslua.

-c
Compile only. Suppresses the linking phase of the compilation. Source code files are turned into compiled files (.ui and .uo), but no executable file is produced. This option is useful for compiling separate units.

-files response-file
Pass the names of files listed in file response-file to the linking phase just as if these names appeared on the command line. File names in response-file are separated by blanks (spaces, tabs, newlines) and must end either in .sml or .uo. A name U.sml appearing in the response file is equivalent to U.uo. Use this option to overcome silly limitations on the length of the command line (as in MS DOS).

-g
This option causes some information about exception names to be written at the end of the executable bytecode file.

-i
Causes the compiler to print the inferred signature of the unit body or bodies being compiled. Also causes the linker to list all object files linked. A U.sig file corresponding to a given U.sml file can be produced semi-automatically by piping the output of the compiler to a file U.out, and subsequently editing this file to obtain a file U.sig.

-noautolink
In version 1.42 and later, the linker automatically links in any additional object files required by the files explicitly specified on the command line. Option -noautolink reinstates the behaviour of pre-1.42 versions: all object files must be explicitly specified in the appropriate order.

-stdlib stdlib-directory
Specifies the standard library directory, which will be searched by the compiler and linker for the .ui and .uo files corresponding to units mentioned in the files being linked. The default standard library is set when the system is created, and is usually ${HOME}/mosml/lib under Unix and c:\mosml\lib under MS Windows and DOS.

-I directory
Add the given directory to the list of directories searched for compiled signature files (.ui) and compiled object code files (.uo). By default, the current directory is searched first, then the standard library directory. Directories added with -I are searched after the current directory, but before the standard library directory. When several directories are added with several -I options on the command line, these directories are searched from left to right.

-valuepoly
Specify that the type checker should use ‘value polymorphism’; see Section 7. Default.

-imptypes
Specify that the type checker should distinguish imperative and applicative type variables, generalize all applicative type variables, and generalize imperative type variables only in non-expansive expressions. See Section 7.

-o exec-file
Specify the name of the output file produced by the linker. In the absence of this option, a default name is used. In MS Windows and DOS, the default name is mosmlout.exe; in Unix it is a.out.

-P unit-set
Determines which library units will be open at compile-time. Any library unit in the load path can be used by the compiler for type checking purposes. Thus regardless of the -P option, the compiler knows the type of library functions such as Array.foldl.

-P default The units Char, List, and String will be partially opened. This is the default, permitting e.g. String.concat to be referred to just as concat.
→P sm190 Provides an initial environment which is upwards compatible with that of the 1990
*Definition of Standard ML* and with pre-1.30 releases of Moscow ML. In particular, the
functions `chr`, `explode`, `implode`, and `ord` work on strings, not characters. The math functions
and input-output facilities required by the 1990 Definition [5, Appendix C and D] are available
at top-level. In addition the same (new) libraries are opened as with →P default.

→P nj93 Provides a top-level environment which is mostly compatible with that of SML/NJ 0.93.
The functions `app`, `ceiling`, `chr`, `dec`, `explode`, `fold`, `hd`, `implode`, `inc`, `max`, `min`, `nth`,
`nthtail`, `ord`, `ordof`, `revapp`, `revfold`, `substring`, `tl`, and `truncate` have the same type
and meaning as in SML/NJ 0.93. The math functions and input-output facilities required by
the 1990 Definition [5, Appendix C and D] are available at top-level. In addition the same
(new) libraries are opened as with →P default. This option does not imply →imptypes.

→P full Same as →P default.

→P none No library units are initially opened.

Additional directories to be searched for library units can be specified with the →I directory option.

→noheader Causes the output file produced by the linker to contain only the bytecode, not preceded by any
executable code. A file mosmlout thus obtained can be executed only by explicitly invoking the
runtime system as follows: `camlrun mosmlout`. This option is primarily used for recompiling the
system.

→q Enables the quotation/antiquotation mechanism; see Section 11.

→v Prints the version number of the various passes of the compiler.

### 6 Recompilation management

Recompilation management helps the programmer recompile only what is necessary after a change to a
unit signature or unit body.

Type-safe linking prevents the programmer from creating unsafe or meaningless programs. The `load`
function and the batch linker ensure probabilistically type-safe linking, so it is virtually impossible to
cause the system to create a type-unsafe program.

#### 6.1 Using ‘make’ to manage recompilation

Consider the example program in Section 4.6 consisting of the three units Evaluate, Expr, and Reduce.
Assume their source files `*.sig` and `*.sml` reside in a particular directory. Copy a Makefile stub (see below)
to that directory, and change to that directory.

1. Edit the Makefile so that the names of the bytecode files `Evaluate.uo`, `Expr.uo`, and `Reduce.uo`
appear on the line beginning with `all:` (see the example makefiles below).
2. Compute the dependencies among the files by executing:
   ```
   make depend
   ```
3. Recompile all those files which have not yet been compiled, or which have been modified but not
   yet recompiled, or which depend on modified files, by executing:
   ```
   make
   ```
Step (3) must be repeated whenever you have modified a component of the program system. Step (2)
need only be repeated if the inter-dependencies of some components change, or if you add or remove
an explicit signature file. Step (1) need only be repeated when you add or delete an entire unit of the
program system.

Old versions of the compiled `*.ui` and `*.uo` files can be removed by executing:
```
make clean
```
The inter-dependencies are computed by a small ML program mosmldep, which correctly handles nested comments and strings in the source files.

6.2 An example Makefile for Unix

To use the Makefile below, first edit it so that all the required units (.uo files) appear on the line beginning with ‘all’, then proceed as explained in Section 6.1. You do not need to edit any other part of the Makefile. In particular, the dependencies following DO NOT DELETE THIS LINE are generated automatically when executing make depend (as above). A copy of the Makefile can be found in mosml/tools/Makefile.stub.

You will need only the Unix utility make.

```make
# Unix Makefile stub for separate compilation with Moscow ML.

MOSMLHOME=${HOME}/mosml
MOSMLTOOLS=$(HOME)/mosml
MOSMLC=mosmlc
MOSMILL=mosml
MOSMLLEX=mosmllex
MOSMLYACC=mosmlacc

.SUFFIXES : .sig .sml .ui .uo
all: Evaluate.uo Expr.uo Reduce.uo

clean:
    rm -f *.ui
    rm -f *.uo
    rm -f Makefile.bak

.sig.ui:
    $(MOSMLC) $<

.sml.uo:
    $(MOSMLC) $<

depend:
    rm -f Makefile.bak
    mv Makefile.bak
    $(MOSMLTOOLS)/cutdeps < Makefile.bak > Makefile
    $(MOSMLTOOLS)/mosmldep >> Makefile

### DO NOT DELETE THIS LINE
Evaluate.ui: Expr.uo
Evaluate.uo: Evaluate.ui Expr.uo Reduce.ui
Reduce.ui: Reduce.ui Expr.uo
Reduce.ui: Expr.uo
```

6.3 An example Makefile for MS DOS

To use the Makefile below, first edit it so that all the required units (.uo files) appear on the line beginning with ‘all’, then proceed as explained in Section 6.1. You do not need to edit any other part of the Makefile. In particular, the dependencies following DO NOT DELETE THIS LINE are generated automatically when executing make depend (as above). A copy of this makefile can be found in mosml\tools\makefile.stub.

You will need a DOS version of make, such as that from Borland C++ version 2.0 or 3.0.
# DOS Makefile stub for separate compilation with Moscow ML.

MOSMLHOME=c:\mosml
MOSMLTOOLS=camlrunm $(MOSMLHOME)\tools
MOSMLC=mosmlc -c
MOSML=mosmlc
MOSMLLEX=mosmllex
MOSMLYACC=mosmlyac

all: evaluate.uo expr.uo reduce.uo

clean:
    del *.ui
    del *.uo
    del makefile.bak

.sig.ui:
    $(MOSMLC) <

.sml.uo:
    $(MOSMLC) <

depend:
    del makefile.bak
    ren makefile makefile.bak
    $(MOSMLTOOLS)\cutdeps < makefile.bak > makefile
    $(MOSMLTOOLS)\mosmldep >> makefile

### DO NOT DELETE THIS LINE
evaluate.uo: evaluate.ui expr.uo reduce.ui
reduce.ui: expr.uo
reduce.uo: reduce.ui expr.uo
evaluate.ui: expr.uo

6.4 Unit names and DOS file names

Recompilation management for DOS is essentially as for Unix, except for the usual complications that follow from the restrictions on the length of file names, and from their case-insensitivity.

Under MS DOS, filenames are all the same case and can be at most 8 characters long (plus a 3 character extension). Since file names are used as unit names, this may cause problems. We attempt to circumvent these problems as follows:

- Unit names used inside ML programs under DOS are 'normalized': the first character is made upper case (if it is a letter), all other characters are made lower case, and the unit name is truncated to eight characters. Hence a unit which resides in file commands.sml can be referred to as unit Commands inside an ML program, and can also be referred to as CommandStructure, etc., since normalization transforms the latter into the former.
- The following names are exceptions to this rule: BasicIO, BinIO, CharArray, CharVector, CommandLine, FileSys, ListPair, OS, StringCvt, Substring, TextIO, Word8Array, Word8Vector: they are normalized precisely as shown in this list. This is to accommodate the SML Basis Library.
- In DOS makefiles, the file names appearing after all: must be all lower case and at most 8 characters long (otherwise 'make' will not work properly). For instance, the unit CharArray must be called chararr in a DOS makefile.
- A unit name given as argument to load, to compile, or to the batch compiler, is truncated and made lower case by DOS as usual, so evaluating load "VeryLongName" will load bytecode file verylong.uo.

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7 Value polymorphism

The 1997 revision of Standard ML [6] adopts value polymorphism, discarding the distinction between imperative ('_a) and applicative ('a) type variables, and generalizing type variables only in non-expansive expressions. Consider a val-binding

val x = e;

With value polymorphism, the free type variables in the type of x are generalized only if the right-hand side e is non-expansive. This is a purely syntactic criterion: an expression is non-expansive if it has the form nexp, defined by the grammar below:

\[
\text{nexp ::= scan} \quad \text{(special constant)} \\
\text{longid} \quad \text{(possibly qualified) identifier} \\
\{ \langle \text{nexprow} \rangle \} \quad \text{record of non-expansive expressions} \\
( \text{nexp}) \quad \text{parenthesized non-expansive expression} \\
\text{con nexp} \quad \text{constructor application, where con is not ref} \\
\text{excon nexp} \quad \text{exception constructor application} \\
\text{nexp : by} \quad \text{typed non-expansive expression} \\
\text{fn match} \quad \text{function abstraction}
\]

\[
\text{nexprow ::= lab = nexp \langle \text{, nexprow} \rangle}
\]

Roughly, a non-expansive expression is just a value, that is, an expression in normal form. For example, the right-hand side \text{length} below is an identifier, and so is non-expansive. Hence the free type variable 'a in the type 'a list \to int of x becomes generalized:

- val x = length; \\
  > val x = fn : 'a list \to int

On the other hand, the right-hand side \text{(fn f \to> f) length} below, although it evaluates to the same value as the previous one, is expansive: it is not derivable from the above grammar. Hence the type variable 'a will not be generalized, and type checking will fail:

- val x = (fn f \to> f) length; \\
  ! Toplevel input: \\
  > val x = (fn f \to> f) length; \\
  ! Value polymorphism: Free type variable at top level

In Standard ML, all type variables in types reported at top-level must be universally quantified; there must be no free type variables. When type checking fails for this reason, there are two remedies: Either (1) insert a type constraint to eliminate the type variables, or (2) eta-expand the right-hand side to make it non-expansive:

- val x1 = (fn f \to> f) length : bool list \to int; \\
  > val x1 = fn : bool list \to int

- val x2 = fn ys =\> (fn f \to> f) length ys; \\
  > val x2 = fn : 'a list \to int

In Moscow ML versions prior to 1.40, the type checker would distinguish imperative and applicative type variables, generalize all applicative type variables, and generalize imperative type variables only in non-expansive expressions, as required by the 1990 Definition [5]. To reinstatet this behaviour, invoke mosml or mosmlc with the option \text{--imptypes}. This is useful for compiling old programs.
8 Weak pointers

Moscow ML supports weak pointers and arrays of weak pointers, using library structure Weak. A weak pointer is a pointer that cannot itself keep an object alive. Hence the object pointed to by a weak pointer may be deallocated by the garbage collector if the object is reachable only by weak pointers.

The interface to arrays of weak pointers is the same as that of standard arrays (structure Array), but the subscript function sub may raise exception Fail if the accessed object is dead. On the other hand, if sub returns a value, it is guaranteed not to die unexpectedly: it will be kept alive by the returned pointer. Also, the weak array iteration functions iterate only over the live elements of the arrays.

One application of weak pointers is to implement hash consing without space leaks. The idea in hash consing is to re-use pairs: whenever a new pair (a, b) is to be built, an auxiliary table is checked to see whether such a pair exists already. If so, the old pair is reused. In some applications, this may conserve much space and time. However, there is a danger of running out of memory because of a space leak: the pair (a, b) cannot be deallocated by the garbage collector because it remains forever reachable from the auxiliary table. To circumvent this problem, one creates a weak pointer from the auxiliary table to the pair, so that the auxiliary table in itself cannot keep the pair alive.

For an example, see mosml/examples/weak. See also the Weak signature; try `help "Weak"`.

9 Dynamic linking of foreign functions

Moscow ML supports dynamic linking of foreign (C) functions, using library structure Dynlib. A library of functions may be written in C and compiled into a dynamically loadable library, using appropriate compiler options. With the Dynlib structure one can load this library and call the C functions from Moscow ML, without recompiling the runtime system.

It is the responsibility of the C functions to access and construct SML values properly, using the macros defined in mosml/src/runtime/mlvalues.h. For this reason, the foreign function interface is included only with the source distribution. As usual, type or storage mistakes in C programs may crash your programs.

The ML garbage collector may run at any time an ML memory allocation is made. This may cause ML values to be moved (from the young generation to the old one). To make sure that ML heap pointers needed by your C function are adjusted correctly by the garbage collector, register them using the Push_roots and Pop_roots macros from runtime/memory.h.

To modify a value in the ML heap, you must use the Modify macro from runtime/memory.h; otherwise you may confuse the incremental garbage collector and crash your program.

When loading the compiled library one must specify the absolute path unless it has been installed as a system library. This may require putting it in a particular directory, such as /lib or /usr/lib, or editing /etc/ld.so.conf and running ldconfig.

To compile Moscow ML with support for dynamic linking, edit file mosml/src/Makefile.inc as indicated there.

For more information, see the examples in directory mosml/src/dynlibs. See also the Dynlib signature; try `help "Dynlib"`.

10 Using GNU gdbm persistent hash tables

Moscow ML provides an interface to GNU gdbm persistent hashtables, via structures Gdbm and Polygdbm. GNU gdbm provides fast access even to very large hashtables stored on disk, ensuring mutual exclusion etc, handy for creating simple databases for use by CGI scripts and similar.

GNU gdbm must be installed, and the interface to GNU gdbm defined in mosml/src/dynlibs/mgdbm must be compiled and installed before Gdbm and Polygdbm can be used. For instructions, see file mosml/src/dynlibs/mgdbm/README.

---

2Thanks to Ken Larsen at Cambridge University, UK and the Technical University of Denmark.
3In version 1.43, Dynlib is supported under Linux, Solaris and OSF/1 only, using the dlopen family of primitives.
4This requires Dynlib and therefore works only with Linux, Solaris and OSF/1 in version 1.43.
11 Quotations and antiquotations

Moscow ML implements quotations, a non-standard language feature useful for embedding object language phrases in ML programs. Quotations are disabled by default. This feature originates in the Standard ML of New Jersey implementation. To enable quotations in the interactive system (mosml), execute $\text{quotation} := \text{true}$. This allows quotations to appear in declarations entered at top-level and in files compiled by the primitive $\text{compile}$. To enable quotations in files compiled with the batch compiler $\text{mosmlc}$, invoke it with option $-q$ as in $\text{mosmlc} -q$.

A quotation is a particular kind of expression and consists of a non-empty sequence of (possibly empty) fragments surrounded by backquotes:

$$\begin{align*}
\text{exp} & ::= \text{'frags'} \quad \text{quotation} \\
\text{frags} & ::= \text{charseq} \quad \text{character sequence} \\
& \quad \text{id frags} \quad \text{antiquotation variable} \\
& \quad (\text{exp}) \text{ frags} \quad \text{antiquotation expression}
\end{align*}$$

A charseq fragment evaluates to \text{QUOTE "charseq"}. An antiquotation fragment \text{"id or "(exp)" evaluates to ANTIQUOTE value} where \text{value} is the value of the variable \text{id} resp. the expression \text{exp}. All antiquotations in a quotation must have the same type ty.

An antiquotation fragment is always surrounded by (possibly empty) quotation fragments; and no two quotation fragments can be adjacent. The entire quotation is parsed before any antiquotation inside it is evaluated. Hence changing the value of Meta.quotation in an antiquotation inside a quotation has no effect on the parsing of the containing quotation.

For an example, say we have written an ML program to analyse C program phrases, and that we want to enter the C declaration `char s[6] = "abcde"'. We could simply define it as a string:

```ml
val phrase = "char s[6] = \"abcde\"";
```

but then we need to escape the quotes (") in the C declaration, which is tiresome. If instead we use a quotation, these escapes are not needed:

```ml
val phrase = 'char s[6] = "abcde"';
```

It evaluates to \text{QUOTE "char s[6] = \"abcde\""} : 'a frag list. Moreover, suppose we want to generate such declarations for other strings than just "abcde", and that we have an abstract syntax for C phrases:

```ml
datatype cprog =
| IntCst of int
| StrCst of string;
```

Then we may replace the string "abcde" by an antiquotation \text{"(StrCst str)"}, and the array dimension 6 by an antiquotation \text{"(IntCst (size str + 1))"}, and make the string str a function parameter:

```ml
fun mkphrase str = 'char s["(IntCst (size str + 1))" = "(StrCst str)"';
```

Evaluating mkphrase "longer" produces the following representation of a C phrase:

\[
\text{QUOTE "char s[", ANTIQUOTE (IntCst 7), QUOTE "] = ", ANTIQUOTE (StrCst "longer"), QUOTE "] : cprog frag list
\]
12 A lexer generator

This section describes mosmllex, a lexer generator which is closely based on camllex from the Caml Light implementation by Xavier Leroy. This documentation is based on that of camllex also.

12.1 Overview

The mosmllex command produces a lexical analyser from a set of regular expressions with attached semantic actions, in the style of lex. Assume that file lexer. lex contains the specification of a lexical analyser. Then executing

mosmllex lexer. lex

produces a file lexer. sml containing Moscow ML code for the lexical analyser. This file defines one lexing function per entry point in the lexer definition. These functions have the same names as the entry points. Lexing functions take as argument a lexer buffer, and return the semantic attribute of the corresponding entry point.

Lexer buffers are an abstract data type implemented in the library unit Lexing. The functions createLexerString and createLexer from unit Lexing create lexer buffers that read from a character string, or any reading function, respectively.

When used in conjunction with a parser generated by moslyac (see Section 13), the semantic actions compute a value belonging to the datatype token defined by the generated parsing unit.

Example uses of mosmllex can be found in directories calc and lexyacc under mosml/examples.

12.2 Hints on using mosmllex

A lexer definition must have a rule to recognize the special symbol eof, meaning end-of-file. In general, a lexer must be able to handle all characters that can appear in the input. This is usually achieved by putting the wildcard case _ at the very end of the lexer definition. If the lexer is to be used with e.g. MS Windows, MS DOS or MacOS files, remember to provide a rule for the carriage-return symbol \r. Most often \r will be treated the same as \n, e.g. as whitespace.

Do not use string constants to define many keywords; this may produce large lexer programs. It is better to let the lexer scan keywords the same way as identifiers and then use an auxiliary function to distinguish between them. For an example, see the keyword function in mosml/examples/lexyacc/Lexer. lex.

12.3 Syntax of lexer definitions

The format of a lexer definition is as follows:

```
{    header }
    let abbrev = regexp
    ...
    let abbrev = regexp
    rule entrypoint =
        parse regexp { action }
        | ...
        | regexp { action }
        and entrypoint =
        parse ...
        and ...
    ;
```

Comments are delimited by (/* and */, as in SML. An abbreviation (abbrev) for a regular expression may refer only to abbreviations that strictly precede it in the list of abbreviations; in particular, abbreviations cannot be recursive.
12.3.1 Header
The header section is arbitrary Moscow ML text enclosed in curly braces \{ and \}. It can be omitted. If it is present, the enclosed text is copied as is at the beginning of the output file lex.aml. Typically, the header section contains the open directives required by the actions, and possibly some auxiliary functions used in the actions.

12.3.2 Entry points
The names of the entry points must be valid ML identifiers.

12.3.3 Regular expressions
The regular expressions regexp are in the style of lex, but with a more ML-like syntax.

`char`
- A character constant, with a syntax similar to that of Moscow ML character constants; see Section 12.3.5. Match the denoted character.
- Match any character.

`eof`
- Match the end of the lexer input.

"string"
- A string constant, with a syntax similar to that of Moscow ML string constants; see Section 12.3.6. Match the denoted string.

[ character-set ]
- Match any single character belonging to the given character set. Valid character sets are: single character constants `c`; ranges of characters `c1` - `c2` (all characters between `c1` and `c2`, inclusive); and the union of two or more character sets, denoted by concatenation.

[ - character-set ]
- Match any single character not belonging to the given character set.

regexp *
- Match the concatenation of zero or more strings that match regexp. (Repetition).

regexp +
- Match the concatenation of one or more strings that match regexp. (Positive repetition).

regexp ?
- Match either the empty string, or a string matching regexp. (Option).

regexp1 | regexp2
- Match any string that matches either regexp1 or regexp2. (Alternative).

regexp1 regexp2
- Match the concatenation of two strings, the first matching regexp1, the second matching regexp2. (Concatenation).

abbrev
- Match the same strings as the regexp in the most recent let-binding of abbrev.

( regexp )
- Match the same strings as regexp.

The operators * and + have highest precedence, followed by ?, then concatenation, then | (alternative).

12.3.4 Actions
An action is an arbitrary Moscow ML expression. An action is evaluated in a context where the identifier lexbuf is bound to the current lexer buffer. Some typical uses of lexbuf in conjunction with the operations on lexer buffers (provided by the Lexing library unit) are listed below.
Lexing.getLexeme lexbuf
Return the matched string.
Lexing.getLexemeChar lexbuf n
Return the n-th character in the matched string. The first character has number 0.
Lexing.getLexemeStart lexbuf
Return the absolute position in the input text of the beginning of the matched string. The first character read from the input text has position 0.
Lexing.getLexemeEnd lexbuf
Return the absolute position in the input text of the end of the matched string. The first character read from the input text has position 0.

entrypoint lexbuf
Here entrypoint is the name of another entry point in the same lexer definition. Recursively call the lexer on the given entry point. Useful for lexing nested comments, for example.

12.3.5 Character constants
A character constant in the lexer definition is delimited by ` (backquote) characters. The two backquotes enclose either a space or a printable character c, different from ` and \, or an escape sequence:

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Character denoted</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>c</code></td>
<td>the character c</td>
</tr>
<tr>
<td><code>\</code>c`</td>
<td>backslash ()</td>
</tr>
<tr>
<td><code>\'</code></td>
<td>backquote (`)</td>
</tr>
<tr>
<td><code>\n</code></td>
<td>newline (LF)</td>
</tr>
<tr>
<td><code>\r</code></td>
<td>return (CR)</td>
</tr>
<tr>
<td><code>\t</code></td>
<td>horizontaltabulation (TAB)</td>
</tr>
<tr>
<td><code>\b</code></td>
<td>backspace (BS)</td>
</tr>
<tr>
<td><code>\^c</code></td>
<td>the ASCII character control-c</td>
</tr>
<tr>
<td><code>\ddd</code></td>
<td>the character with ASCII code ddd in decimal</td>
</tr>
</tbody>
</table>

12.3.6 String constants
A string constant is a (possibly empty) sequence of characters delimited by " (double quote) characters.

```
string-literal ::= '"strcharseq" non-empty string
                "" empty string
```

strcharseq ::= strchar (strcharseq) character sequence

A string character strchar is either a space or a printable character c, different from " and \, or an escape sequence:

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Character denoted</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>c</code></td>
<td>the character c</td>
</tr>
<tr>
<td><code>\</code></td>
<td>backslash ()</td>
</tr>
<tr>
<td>&quot;&quot;</td>
<td>double quote (&quot;&quot;)</td>
</tr>
<tr>
<td><code>n</code></td>
<td>newline (LF)</td>
</tr>
<tr>
<td><code>r</code></td>
<td>return (CR)</td>
</tr>
<tr>
<td><code>t</code></td>
<td>horizontaltabulation (TAB)</td>
</tr>
<tr>
<td><code>b</code></td>
<td>backspace (BS)</td>
</tr>
<tr>
<td><code>^c</code></td>
<td>the ASCII character control-c</td>
</tr>
<tr>
<td><code>ddd</code></td>
<td>the character with ASCII code ddd in decimal</td>
</tr>
</tbody>
</table>
13 A parser generator

This section describes mosmlyac, a simple parser generator which is closely based on camlyacc from the Caml Light implementation by Xavier Leroy; camlyacc in turn is based on Bob Corbett's public domain Berkeley yacc. This documentation is based on that in the Caml Light reference manual.

13.1 Overview

The mosmlyac command produces a parser from a context-free grammar specification with attached semantic actions, in the style of yacc. Assume file grammar.grm contains a grammar specification; then executing

    mosmlyac grammar.grm

produces a file grammar.sml containing a Moscow ML unit with code for a parser and a file grammar.sig containing its interface.

The generated unit defines a parsing function \( S \) for each start symbol \( S \) declared in the grammar. Each parsing function takes as arguments a lexical analyser (a function from lexer buffers to tokens) and a lexer buffer, and returns the semantic attribute of the corresponding entry point. Lexical analyser functions are usually generated from a lexer specification by the mosmllex program. Lexer buffers are an abstract data type implemented in the library unit Lexing. Tokens are values from the datatype token, defined in the signature file grammar.sig produced by running mosmlyac.

Example uses of mosmlyac can be found in directories calc and lexyacc under mosml/examples.

13.2 The format of grammar definitions

\%
{ %header
%}

declarations
%

rules
%

trailer

Comments in the declarations and rules sections are enclosed in C comment delimiters ///* and /*//, whereas comments in the header and trailer sections are enclosed in ML comment delimiters (* and *).

13.2.1 Header and trailer

Any SML code in the header is copied to the beginning of file grammar.sml, after the token datatype declaration; it usually contains open declarations required by the semantic actions of the rules. Any SML code in the trailer is copied to the end of file grammar.sml. Both sections are optional.

13.2.2 Declarations

Declarations are given one per line. They all start with a % sign.

%token symbol ... symbol

Declare the given symbols as tokens (terminal symbols). These symbols become constructors (without arguments) in the token datatype.

%token < type > symbol ... symbol

Declare the given symbols as tokens with an attached attribute of the given type. These symbols become constructors (with arguments of the given type) in the token datatype. The type part is an arbitrary Moscow ML type expression, but all type constructor names must be fully qualified (e.g. Unitname.typename) for all types except standard built-in types, even if the proper open declarations (e.g. open Unitname) were given in the header section.
Declare the given symbol as entry point for the grammar. For each entry point, a parsing function with the same name is defined in the output file `grammar.sml`. Non-terminals that are not declared as entry points have no such parsing function.

%type < type > symbol ... symbol

Specify the type of the semantic attributes for the given symbols. Every non-terminal symbol, including the start symbols, must have the type of its semantic attribute declared this way. This ensures that the generated parser is type-safe. The type part may be an arbitrary Moscow ML type expression, but all type constructor names must be fully qualified (e.g. `Unitname.type name`) for all types except standard built-in types, even if the proper open declaration (e.g. `open Unitname`) were given in the header section.

%left symbol ... symbol
%right symbol ... symbol
%nonassoc symbol ... symbol

Declare the precedence and associativity of the given symbols. All symbols on the same line are given the same precedence. They have higher precedence than symbols declared in previous `%left`, `%right` or `%nonassoc` lines. They have lower precedence than symbols declared in subsequent `%left`, `%right` or `%nonassoc` lines. The symbols are declared to associate to the left (`%left`), to the right (`%right`), or to be non-associative (`%nonassoc`). The symbols are usually tokens, but can also be dummy non-terminals, for use with the `%prec` directive inside the rules.

13.2.3 The format of grammar rules

nonterminal :
  symbol ... symbol { semantic-action }
  | ...
  | symbol ... symbol { semantic-action }

Each right-hand side consists of a (possibly empty) sequence of symbols, followed by a semantic action.

The directive `%prec symbol` may occur among the symbols in a rule right-hand side, to specify that the rule has the same precedence and associativity as the given symbol.

Semantic actions are arbitrary Moscow ML expressions, which are evaluated to produce the semantic attribute attached to the defined nonterminal. The semantic actions can access the semantic attributes of the symbols in the right-hand side of the rule with the $ notation: $1 is the attribute of the first (leftmost) symbol, $2 is the attribute of the second symbol, etc. An empty semantic action evaluates to ( ) : unit.

Actions occurring in the middle of rules are not supported. Error recovery is not implemented.

13.3 Command-line options of mosmlyac

-v
  Generate a description of the parsing tables and a report on conflicts resulting from ambiguities in the grammar. The description is put in file `grammar.output`.

-bprefix
  Name the output files `prefix.sml`, `prefix.sig`, `prefix.output`, instead of using the default naming convention.

13.4 Reporting lexer and parser errors

Lexical errors (e.g. illegal symbols) and syntax errors can be reported in an intelligible way by using the Location module from the Moscow ML library. It provides functions to print out fragments of a source text, using location information from the lexer and parser. See help "Location.sig" for more information. See file `mosml/examples/lelyacc/Main.sml` for an example.
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- the CAML Light implementation by Xavier Leroy and Damien Doligez (INRIA, Rocquencourt, France);
- the ML Kit by Lars Birkedal, Nick Rothwell, Mads Tofte and David Turner (Copenhagen University, Denmark, and Edinburgh University, Scotland);
- inspiration from the SML/NJ compiler developed at Princeton University and AT&T Bell Laboratories, New Jersey, USA; and
- the good work by Doug Currie, Flavors Technology, USA, on the MacOS port.

15 How to get Moscow ML version 1.43

- The Moscow ML home page is http://www.dina.kvl.dk/~sestoft/mosml.html
- The Linux executables are in ftp://ftp.dina.kvl.dk/pub/mosml/linux-mos14bin.tar.gz
- The MS Windows executables are in ftp://ftp.dina.kvl.dk/pub/mosml/win32-mos14bin.zip
- The MS DOS executables are in ftp://ftp.dina.kvl.dk/pub/mosml/mos14bin.zip
- The Macintosh/MacOS (68k and PPC) executables are in ftp://ftp.dina.kvl.dk/pub/mosml/mac-mos14bin.sea.hqx
- The DOS source files are in ftp://ftp.dina.kvl.dk/pub/mosml/mos14src.zip
- The Unix and MS Windows source files are in ftp://ftp.dina.kvl.dk/pub/mosml/mos14src.tar.gz
- The MacOS modified source files (relative to Unix) are in ftp://ftp.dina.kvl.dk/pub/mosml/mac-mos14src.sea.hqx
- The MkLinux executables and binaries are available at http://www.ibg.uu.se/mkarchive/dev/lang

The files are mirrored at ftp://ftp.csd.uu.se/pub/mirror/mosml.
16 Books and other materials on Standard ML

The Definition and Commentary


Textbooks available from publishers


Texts available on the net

  http://www.dina.kvl.dk/~sestoft/sml/sml-std-basis.html (mirror site)

References