MLton Guide (20180207)

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Abstract

This is the guide for MLton, an open-source, whole-program, optimizing Standard ML compiler.

This guide was generated automatically from the MLton website, available online at http://mlton.org. It is up to date for MLton 20180207.

MLton

What is MLton?

MLton is an open-source, whole-program, optimizing Standard ML compiler.

What's new?

- 20180207: Please try out our latest release, MLton 20180207.
- 20140730: Matthew Fluet and Lukasz Ziarek have been awarded an NSF CISE Research Infrastructure (CRI) grant titled "Positioning MLton for Next-Generation Programming Languages Research;" read the award abstracts (Award #1405770 and Award #1405614) for more details.

Next steps

- Read about MLton's Features.
- Look at Documentation.
- See some Users of MLton.
- Download MLton.
- Meet the MLton Developers.
- Get involved with MLton Development.
- User-maintained FAQ.
- Contact us.

AdamGoode

- I maintain the Fedora package of MLton, in Fedora.
- I have contributed some patches for Makefiles and PDF documentation building.

AdmitsEquality

A TypeConstructor admits equality if whenever it is applied to equality types, the result is an EqualityType. This notion enables one to determine whether a type constructor application yields an equality type solely from the application, without looking at the definition of the type constructor. It helps to ensure that PolymorphicEquality is only applied to sensible values.

The definition of admits equality depends on whether the type constructor was declared by a `type` definition or a `datatype` declaration.

Type definitions

For type definition

```
type ('a1, ..., 'an) t = ...
```

type constructor `t` admits equality if the right-hand side of the definition is an equality type after replacing `'a1`, ..., `'an` by equality types (it doesn't matter which equality types are chosen).

For a nullary type definition, this amounts to the right-hand side being an equality type. For example, after the definition

```
type t = bool * int
```

type constructor `t` admits equality because `bool * int` is an equality type. On the other hand, after the definition

```
type t = bool * int * real
```

type constructor `t` does not admit equality, because `real` is not an equality type.

For another example, after the definition

```
type 'a t = bool * 'a
```

type constructor `t` admits equality because `bool * int` is an equality type (we could have chosen any equality type other than `int`).

On the other hand, after the definition

```
type 'a t = real * 'a
```

type constructor `t` does not admit equality because `real * int` is not equality type.

We can check that a type constructor admits equality using an `eqtype` specification.

```
structure Ok: sig eqtype 'a t end =
   struct
      type 'a t = bool * 'a
   end
```

```
structure Bad: sig eqtype 'a t end =
   struct
      type 'a t = real * int * 'a
   end
```

On `structure Bad`, MLton reports the following error.

```
Error: z.sml 1.16-1.34.
  Type in structure disagrees with signature (admits equality): t.
    structure: type 'a t = [real] * _ * _
    defn at: z.sml 3.15-3.15
    signature: [eqtype] 'a t
    spec at: z.sml 1.30-1.30
```

The `structure:` section provides an explanation of why the type did not admit equality, highlighting the problematic component (`real`).

Datatype declarations

For a type constructor declared by a datatype declaration to admit equality, every variant of the datatype must admit equality. For example, the following datatype admits equality because `bool` and `char * int` are equality types.

```
datatype t = A of bool | B of char * int
```

Nullary constructors trivially admit equality, so that the following datatype admits equality.

```
datatype t = A | B | C
```

For a parameterized datatype constructor to admit equality, we consider each variant as a type definition, and require that the definition admit equality. For example, for the datatype

```
datatype 'a t = A of bool * 'a | B of 'a
```

the type definitions

```
type 'a tA = bool * 'a
type 'a tB = 'a
```

both admit equality. Thus, type constructor `t` admits equality.

On the other hand, the following datatype does not admit equality.

```
datatype 'a t = A of bool * 'a | B of real * 'a
```

As with type definitions, we can check using an `eqtype` specification.

```
structure Bad: sig eqtype 'a t end =
   struct
      datatype 'a t = A of bool * 'a | B of real * 'a
   end
```

MLton reports the following error.

```
Error: z.sml 1.16-1.34.
  Type in structure disagrees with signature (admits equality): t.
    structure: datatype 'a t = B of [real] * _ | ...
    defn at: z.sml 3.19-3.19
    signature: [eqtype] 'a t
    spec at: z.sml 1.30-1.30
```

MLton indicates the problematic constructor (`B`), as well as the problematic component of the constructor's argument.

Recursive datatypes

A recursive datatype like

```
datatype t = A | B of int * t
```

introduces a new problem, since in order to decide whether `t` admits equality, we need to know for the `B` variant whether `t` admits equality. The Definition answers this question by requiring a type constructor to admit equality if it is consistent to do so. So, in our above example, if we assume that `t` admits equality, then the variant `B of int * t` admits equality. Then, since the `A` variant trivially admits equality, so does the type constructor `t`. Thus, it was consistent to assume that `t` admits equality, and so, `t` does admit equality.

On the other hand, in the following declaration

```
datatype t = A | B of real * t
```

if we assume that `t` admits equality, then the `B` variant does not admit equality. Hence, the type constructor `t` does not admit equality, and our assumption was inconsistent. Hence, `t` does not admit equality.

The same kind of reasoning applies to mutually recursive datatypes as well. For example, the following defines both `t` and `u` to admit equality.

```
datatype t = A | B of u
and u = C | D of t
```

But the following defines neither `t` nor `u` to admit equality.

```
datatype t = A | B of u * real
and u = C | D of t
```

As always, we can check whether a type admits equality using an `eqtype` specification.

```
structure Bad: sig eqtype t eqtype u end =
   struct
      datatype t = A | B of u * real
      and u = C | D of t
   end
```

MLton reports the following error.

```
Error: z.sml 1.16-1.40.
  Type in structure disagrees with signature (admits equality): t.
    structure: datatype t = B of [_str.u] * [real] | ...
    defn at: z.sml 3.16-3.16
    signature: [eqtype] t
    spec at: z.sml 1.27-1.27
Error: z.sml 1.16-1.40.
  Type in structure disagrees with signature (admits equality): u.
    structure: datatype u = D of [_str.t] | ...
    defn at: z.sml 4.11-4.11
    signature: [eqtype] u
    spec at: z.sml 1.36-1.36
```

Alice

Alice ML is an extension of SML with concurrency, dynamic typing, components, distribution, and constraint solving.

AllocateRegisters

AllocateRegisters is an analysis pass for the RSSA IntermediateLanguage, invoked from ToMachine.

Description

Computes an allocation of RSSA variables as Machine register or stack operands.

Implementation

- `allocate-registers.sig`
- `allocate-registers.fun`

Details and Notes

AndreiFormiga

I'm a graduate student just back in academia. I study concurrent and parallel systems, with a great deal of interest in programming languages (theory, design, implementation). I happen to like functional languages.

I use the nickname tautologico on #sml and my email is andrei DOT formiga AT gmail DOT com.

ArrayLiteral

Standard ML does not have a syntax for array literals or vector literals. The only way to write down an array is like

```
Array.fromList [w, x, y, z]
```

No SML compiler produces efficient code for the above expression. The generated code allocates a list and then converts it to an array. To alleviate this, one could write down the same array using `Array.tabulate`, or even using `Array.array` and `Array.update`, but that is syntactically unwieldy.

Fortunately, using Fold, it is possible to define constants `A`, and `` ` `` so that one can write down an array like:

```
A `w `x `y `z $
```

This is as syntactically concise as the `fromList` expression. Furthermore, MLton, at least, will generate the efficient code as if one had written down a use of `Array.array` followed by four uses of `Array.update`.

Along with `A` and `` ` ``, one can define a constant `V` that makes it possible to define vector literals with the same syntax, e.g.,

```
V `w `x `y `z $
```

Note that the same element indicator, `` ` ``, serves for both array and vector literals. Of course, the `$` is the end-of-arguments marker always used with Fold. The only difference between an array literal and vector literal is the `A` or `V` at the beginning.

Here is the implementation of `A`, `V`, and `` ` ``. We place them in a structure and use signature abstraction to hide the type of the accumulator. See Fold for more on this technique.

```
structure Literal:>
   sig
      type 'a z
      val A: ('a z, 'a z, 'a array, 'd) Fold.t
      val V: ('a z, 'a z, 'a vector, 'd) Fold.t
      val ` : ('a, 'a z, 'a z, 'b, 'c, 'd) Fold.step1
   end =
   struct
      type 'a z = int * 'a option * ('a array -> unit)

      val A =
         fn z =>
         Fold.fold
         ((0, NONE, ignore),
          fn (n, opt, fill) =>
          case opt of
             NONE =>
                Array.tabulate (0, fn _ => raise Fail "array0")
           | SOME x =>
                let
                   val a = Array.array (n, x)
                   val () = fill a
                in
                   a
                end)
         z

      val V = fn z => Fold.post (A, Array.vector) z

      val ` =
         fn z =>
         Fold.step1
         (fn (x, (i, opt, fill)) =>
          (i + 1,
           SOME x,
```

```
          fn a => (Array.update (a, i, x); fill a)))
        z
   end
```

The idea of the code is for the fold to accumulate a count of the number of elements, a sample element, and a function that fills in all the elements. When the fold is complete, the finishing function allocates the array, applies the fill function, and returns the array. The only difference between `A` and `V` is at the very end; `A` just returns the array, while `V` converts it to a vector using post-composition, which is further described on the Fold page.

AST

AST is the IntermediateLanguage produced by the FrontEnd and translated by Elaborate to CoreML.

Description

The abstract syntax tree produced by the FrontEnd.

Implementation

- ast-programs.sig
- ast-programs.fun
- ast-modules.sig
- ast-modules.fun
- ast-core.sig
- ast-core.fun
- ast

Type Checking

The AST IntermediateLanguage has no independent type checker. Type inference is performed on an AST program as part of Elaborate.

Details and Notes

Source locations

MLton makes use of a relatively clean method for annotating the abstract syntax tree with source location information. Every source program phrase is "wrapped" with the `WRAPPED` interface:

```
signature WRAPPED =
   sig
      type node'
      type obj

      val dest: obj -> node' * Region.t
      val makeRegion': node' * SourcePos.t * SourcePos.t -> obj
      val makeRegion: node' * Region.t -> obj
      val node: obj -> node'
      val region: obj -> Region.t
   end
```

The key idea is that `node'` is the type of an unannotated syntax phrase and `obj` is the type of its annotated counterpart. In the implementation, every `node'` is annotated with a `Region.t` (region.sig, region.sml), which describes the syntax phrase's left source position and right source position, where `SourcePos.t` (source-pos.sig, source-pos.sml) denotes a particular file, line, and column. A typical use of the `WRAPPED` interface is illustrated by the following code:

```
            datatype node =
               App of Longcon.t * t
             | Const of Const.t
             | Constraint of t * Type.t
             | FlatApp of t vector
             | Layered of {constraint: Type.t option,
                           fixop: Fixop.t,
                           pat: t,
                           var: Var.t}
             | List of t vector
             | Paren of t
             | Or of t vector
             | Record of {flexible: bool,
                          items: (Record.Field.t * Region.t * Item.t) vector}
             | Tuple of t vector
             | Var of {fixop: Fixop.t,
                       name: Longvid.t}
             | Vector of t vector
             | Wild
```

Thus, AST nodes are cleanly separated from source locations. By way of contrast, consider the approach taken by SML/NJ (and also by the CKit Library). Each datatype denoting a syntax phrase dedicates a special constructor for annotating source locations:

```
datatype pat = WildPat                              (* empty pattern *)
             | AppPat of {constr:pat,argument:pat}  (* application *)
             | MarkPat of pat * region              (* mark a pattern *)
```

The main drawback of this approach is that static type checking is not sufficient to guarantee that the AST emitted from the front-end is properly annotated.

BasisLibrary

The Standard ML Basis Library is a collection of modules dealing with basic types, input/output, OS interfaces, and simple datatypes. It is intended as a portable library usable across all implementations of SML. For the official online version of the Basis Library specification, see http://www.standardml.org/Basis. The Standard ML Basis Library is a book version that includes all of the online version and more. For a reverse chronological list of changes to the specification, see http://www.standardml.org/-Basis/history.html.

MLton implements all of the required portions of the Basis Library. MLton also implements many of the optional structures. You can obtain a complete and current list of what's available using `mlton -show-basis` (see ShowBasis). By default, MLton makes the Basis Library available to user programs. You can also access the Basis Library from ML Basis files.

Below is a complete list of what MLton implements.

Top-level types and constructors

```
eqtype 'a array
datatype bool =false | true
eqtype char
type exn
eqtype int
datatype 'a list =nil | ::of ('a * 'a list)
datatype 'a option =NONE | SOME of 'a
datatype order =EQUAL | GREATER | LESS
type real
datatype 'a ref =ref of 'a
eqtype string
type substring
eqtype unit
eqtype 'a vector
eqtype word
```

Top-level exception constructors

```
Bind
Chr
Div
Domain
Empty
Fail of string
Match
Option
Overflow
Size
Span
Subscript
```

Top-level values

MLton does not implement the optional top-level value `use:string -> unit`, which conflicts with whole-program compilation because it allows new code to be loaded dynamically.

MLton implements all other top-level values:

`!`, `:=`, `<>`, `=`, `@`, `^`, `app`, `before`, `ceil`, `chr`, `concat`, `exnMessage`, `exnName`, `explode`, `floor`, `foldl`, `foldr`, `getOpt`, `hd`, `ignore`, `implode`, `isSome`, `length`, `map`, `not`, `null`, `o`, `ord`, `print`, `real`, `rev`, `round`, `size`, `str`, `substring`, `tl`, `trunc`, `valOf`, `vector`

Overloaded identifiers

`*`, `+`, `-`, `/`, `<`, `<=`, `>`, `>=`, `~`, `abs`, `div`, `mod`

Top-level signatures

ARRAY

ARRAY2

ARRAY_SLICE

BIN_IO

BIT_FLAGS

BOOL

BYTE

CHAR

COMMAND_LINE

DATE

GENERAL

GENERIC_SOCK

IEEE_REAL

IMPERATIVE_IO

INET_SOCK

INTEGER

INT_INF

IO

LIST

LIST_PAIR

MATH

MONO_ARRAY

MONO_ARRAY2

MONO_ARRAY_SLICE

MONO_VECTOR

MONO_VECTOR_SLICE

NET_HOST_DB

NET_PROT_DB

NET_SERV_DB

OPTION

OS

OS_FILE_SYS

OS_IO

OS_PATH

OS_PROCESS

PACK_REAL

PACK_WORD

POSIX

POSIX_ERROR

POSIX_FILE_SYS

POSIX_IO

POSIX_PROCESS

POSIX_PROC_ENV

POSIX_SIGNAL

POSIX_SYS_DB

POSIX_TTY

PRIM_IO

REAL

SOCKET

STREAM_IO

STRING

STRING_CVT

SUBSTRING

TEXT

TEXT_IO

TEXT_STREAM_IO

TIME

TIMER

UNIX

UNIX_SOCK

VECTOR

VECTOR_SLICE

WORD

Top-level structures

`structure Array:ARRAY`

`structure Array2:ARRAY2`

`structure ArraySlice:ARRAY_SLICE`

`structure BinIO:BIN_IO`

`structure BinPrimIO:PRIM_IO`

`structure Bool:BOOL`

`structure BoolArray:MONO_ARRAY`

`structure BoolArray2:MONO_ARRAY2`

`structure BoolArraySlice:MONO_ARRAY_SLICE`

`structure BoolVector:MONO_VECTOR`

`structure BoolVectorSlice:MONO_VECTOR_SLICE`

`structure Byte:BYTE`

`structure Char:CHAR`

- `Char` characters correspond to ISO-8859-1. The `Char` functions do not depend on locale.

`structure CharArray:MONO_ARRAY`

`structure CharArray2:MONO_ARRAY2`

`structure CharArraySlice:MONO_ARRAY_SLICE`

`structure CharVector:MONO_VECTOR`

`structure CharVectorSlice:MONO_VECTOR_SLICE`

`structure CommandLine:COMMAND_LINE`

`structure Date:DATE`

- `Date.fromString` and `Date.scan` accept a space in addition to a zero for the first character of the day of the month. The Basis Library specification only allows a zero.

`structure FixedInt:INTEGER`

`structure General:GENERAL`

`structure GenericSock:GENERIC_SOCK`

`structure IEEEReal:IEEE_REAL`

`structure INetSock:INET_SOCK`

`structure IO:IO`

`structure Int:INTEGER`

`structure Int1:INTEGER`

`structure Int2:INTEGER`

`structure Int3:INTEGER`

`structure Int4:INTEGER`

...

`structure Int31:INTEGER`

```
structure Int32:INTEGER
structure Int64:INTEGER
structure IntArray:MONO_ARRAY
structure IntArray2:MONO_ARRAY2
structure IntArraySlice:MONO_ARRAY_SLICE
structure IntVector:MONO_VECTOR
structure IntVectorSlice:MONO_VECTOR_SLICE
structure Int8:INTEGER
structure Int8Array:MONO_ARRAY
structure Int8Array2:MONO_ARRAY2
structure Int8ArraySlice:MONO_ARRAY_SLICE
structure Int8Vector:MONO_VECTOR
structure Int8VectorSlice:MONO_VECTOR_SLICE
structure Int16:INTEGER
structure Int16Array:MONO_ARRAY
structure Int16Array2:MONO_ARRAY2
structure Int16ArraySlice:MONO_ARRAY_SLICE
structure Int16Vector:MONO_VECTOR
structure Int16VectorSlice:MONO_VECTOR_SLICE
structure Int32:INTEGER
structure Int32Array:MONO_ARRAY
structure Int32Array2:MONO_ARRAY2
structure Int32ArraySlice:MONO_ARRAY_SLICE
structure Int32Vector:MONO_VECTOR
structure Int32VectorSlice:MONO_VECTOR_SLICE
structure Int64Array:MONO_ARRAY
structure Int64Array2:MONO_ARRAY2
structure Int64ArraySlice:MONO_ARRAY_SLICE
structure Int64Vector:MONO_VECTOR
structure Int64VectorSlice:MONO_VECTOR_SLICE
structure IntInf:INT_INF
structure LargeInt:INTEGER
structure LargeIntArray:MONO_ARRAY
structure LargeIntArray2:MONO_ARRAY2
structure LargeIntArraySlice:MONO_ARRAY_SLICE
structure LargeIntVector:MONO_VECTOR
structure LargeIntVectorSlice:MONO_VECTOR_SLICE
structure LargeReal:REAL
structure LargeRealArray:MONO_ARRAY
```

```
structure LargeRealArray2:MONO_ARRAY2
structure LargeRealArraySlice:MONO_ARRAY_SLICE
structure LargeRealVector:MONO_VECTOR
structure LargeRealVectorSlice:MONO_VECTOR_SLICE
structure LargeWord:WORD
structure LargeWordArray:MONO_ARRAY
structure LargeWordArray2:MONO_ARRAY2
structure LargeWordArraySlice:MONO_ARRAY_SLICE
structure LargeWordVector:MONO_VECTOR
structure LargeWordVectorSlice:MONO_VECTOR_SLICE
structure List:LIST
structure ListPair:LIST_PAIR
structure Math:MATH
structure NetHostDB:NET_HOST_DB
structure NetProtDB:NET_PROT_DB
structure NetServDB:NET_SERV_DB
structure OS:OS
structure Option:OPTION
structure PackReal32Big:PACK_REAL
structure PackReal32Little:PACK_REAL
structure PackReal64Big:PACK_REAL
structure PackReal64Little:PACK_REAL
structure PackRealBig:PACK_REAL
structure PackRealLittle:PACK_REAL
structure PackWord16Big:PACK_WORD
structure PackWord16Little:PACK_WORD
structure PackWord32Big:PACK_WORD
structure PackWord32Little:PACK_WORD
structure PackWord64Big:PACK_WORD
structure PackWord64Little:PACK_WORD
structure Position:INTEGER
structure Posix:POSIX
structure Real:REAL
structure RealArray:MONO_ARRAY
structure RealArray2:MONO_ARRAY2
structure RealArraySlice:MONO_ARRAY_SLICE
structure RealVector:MONO_VECTOR
structure RealVectorSlice:MONO_VECTOR_SLICE
structure Real32:REAL
```

`structure Real32Array:MONO_ARRAY`

`structure Real32Array2:MONO_ARRAY2`

`structure Real32ArraySlice:MONO_ARRAY_SLICE`

`structure Real32Vector:MONO_VECTOR`

`structure Real32VectorSlice:MONO_VECTOR_SLICE`

`structure Real64:REAL`

`structure Real64Array:MONO_ARRAY`

`structure Real64Array2:MONO_ARRAY2`

`structure Real64ArraySlice:MONO_ARRAY_SLICE`

`structure Real64Vector:MONO_VECTOR`

`structure Real64VectorSlice:MONO_VECTOR_SLICE`

`structure Socket:SOCKET`

- The Basis Library specification requires functions like `Socket.sendVec` to raise an exception if they fail. However, on some platforms, sending to a socket that hasn't yet been connected causes a `SIGPIPE` signal, which invokes the default signal handler for `SIGPIPE` and causes the program to terminate. If you want the exception to be raised, you can ignore `SIGPIPE` by adding the following to your program.

```
let
   open MLton.Signal
in
   setHandler (Posix.Signal.pipe, Handler.ignore)
end
```

`structure String:STRING`

- The `String` functions do not depend on locale.

`structure StringCvt:STRING_CVT`

`structure Substring:SUBSTRING`

`structure SysWord:WORD`

`structure Text:TEXT`

`structure TextIO:TEXT_IO`

`structure TextPrimIO:PRIM_IO`

`structure Time:TIME`

`structure Timer:TIMER`

`structure Unix:UNIX`

`structure UnixSock:UNIX_SOCK`

`structure Vector:VECTOR`

`structure VectorSlice:VECTOR_SLICE`

`structure Word:WORD`

`structure Word1:WORD`

`structure Word2:WORD`

`structure Word3:WORD`

structure Word4:WORD

...

structure Word31:WORD

structure Word32:WORD

structure Word64:WORD

structure WordArray:MONO_ARRAY

structure WordArray2:MONO_ARRAY2

structure WordArraySlice:MONO_ARRAY_SLICE

structure WordVectorSlice:MONO_VECTOR_SLICE

structure WordVector:MONO_VECTOR

structure Word8Array:MONO_ARRAY

structure Word8Array2:MONO_ARRAY2

structure Word8ArraySlice:MONO_ARRAY_SLICE

structure Word8Vector:MONO_VECTOR

structure Word8VectorSlice:MONO_VECTOR_SLICE

structure Word16Array:MONO_ARRAY

structure Word16Array2:MONO_ARRAY2

structure Word16ArraySlice:MONO_ARRAY_SLICE

structure Word16Vector:MONO_VECTOR

structure Word16VectorSlice:MONO_VECTOR_SLICE

structure Word32Array:MONO_ARRAY

structure Word32Array2:MONO_ARRAY2

structure Word32ArraySlice:MONO_ARRAY_SLICE

structure Word32Vector:MONO_VECTOR

structure Word32VectorSlice:MONO_VECTOR_SLICE

structure Word64Array:MONO_ARRAY

structure Word64Array2:MONO_ARRAY2

structure Word64ArraySlice:MONO_ARRAY_SLICE

structure Word64Vector:MONO_VECTOR

structure Word64VectorSlice:MONO_VECTOR_SLICE

Top-level functors

ImperativeIO

PrimIO

StreamIO

- MLton's `StreamIO` functor takes structures `ArraySlice` and `VectorSlice` in addition to the arguments specified in the Basis Library specification.

Type equivalences

The following types are equivalent.

```
FixedInt = Int64.int
LargeInt = IntInf.int
LargeReal.real = Real64.real
LargeWord = Word64.word
```

The default `int`, `real`, and `word` types may be set by the `-default-type` *`type`* compile-time option. By default, the following types are equivalent:

```
int = Int.int = Int32.int
real = Real.real = Real64.real
word = Word.word = Word32.word
```

Real and Math functions

The `Real`, `Real32`, and `Real64` modules are implemented using the `C` math library, so the SML functions will reflect the behavior of the underlying library function. We have made some effort to unify the differences between the math libraries on different platforms, and in particular to handle exceptional cases according to the Basis Library specification. However, there will be differences due to different numerical algorithms and cases we may have missed. Please submit a bug report if you encounter an error in the handling of an exceptional case.

On x86, real arithmetic is implemented internally using 80 bits of precision. Using higher precision for intermediate results in computations can lead to different results than if all the computation is done at 32 or 64 bits. If you require strict IEEE compliance, you can compile with `-ieee-fp true`, which will cause intermediate results to be stored after each operation. This may cause a substantial performance penalty.

Bug

To report a bug, please send mail to `mlton-devel@mlton.org`. Please include the complete SML program that caused the problem and a log of a compile of the program with `-verbose 2`. For large programs (over 256K), please send an email containing the discussion text and a link to any large files.

There are some UnresolvedBugs that we don't plan to fix.

We also maintain a list of bugs found with each release.

- Bugs20130715
- Bugs20100608
- Bugs20070826
- Bugs20051202
- Bugs20041109

Bugs20041109

Here are the known bugs in MLton 20041109, listed in reverse chronological order of date reported.

- `MLton.Finalizable.touch` doesn't necessarily keep values alive long enough. Our SVN has a patch to the compiler. You must rebuild the compiler in order for the patch to take effect.

  Thanks to Florian Weimer for reporting this bug.

- A bug in an optimization pass may incorrectly transform a program to flatten ref cells into their containing data structure, yielding a type-error in the transformed program. Our CVS has a patch to the compiler. You must rebuild the compiler in order for the patch to take effect.

  Thanks to VesaKarvonen for reporting this bug.

- A bug in the front end mistakenly allows unary constructors to be used without an argument in patterns. For example, the following program is accepted, and triggers a large internal error.

  ```
  fun f x = case x of SOME => true | _ => false
  ```

  We have fixed the problem in our CVS.

  Thanks to William Lovas for reporting this bug.

- A bug in `Posix.IO.{getlk,setlk,setlkw}` causes a link-time error: `undefined reference to Posix_IO_FLock_typ` Our CVS has a patch to the Basis Library implementation.

  Thanks to Adam Chlipala for reporting this bug.

- A bug can cause programs compiled with `-profile alloc` to segfault. Our CVS has a patch to the compiler. You must rebuild the compiler in order for the patch to take effect.

  Thanks to John Reppy for reporting this bug.

- A bug in an optimization pass may incorrectly flatten ref cells into their containing data structure, breaking the sharing between the cells. Our CVS has a patch to the compiler. You must rebuild the compiler in order for the patch to take effect.

  Thanks to Paul Govereau for reporting this bug.

- Some arrays or vectors, such as `(char * char) vector`, are incorrectly implemented, and will conflate the first and second components of each element. Our CVS has a patch to the compiler. You must rebuild the compiler in order for the patch to take effect.

  Thanks to Scott Cruzen for reporting this bug.

- `Socket.Ctl.getLINGER` and `Socket.Ctl.setLINGER` mistakenly raise `Subscript`. Our CVS has a patch to the Basis Library implementation.

  Thanks to Ray Racine for reporting the bug.

- CML `Mailbox.send` makes a call in the wrong atomic context. Our CVS has a patch to the CML implementation.

- `OS.Path.joinDirFile` and `OS.Path.toString` did not raise `InvalidArc` when they were supposed to. They now do. Our CVS has a patch to the Basis Library implementation.

  Thanks to Andreas Rossberg for reporting the bug.

- The front end incorrectly disallows sequences of expressions (separated by semicolons) after a topdec has already been processed. For example, the following is incorrectly rejected.

  ```
  val x = 0;
  ignore x;
  ignore x;
  ```

  We have fixed the problem in our CVS.

  Thanks to Andreas Rossberg for reporting the bug.

- The front end incorrectly disallows expansive `val` declarations that bind a type variable that doesn't occur in the type of the value being bound. For example, the following is incorrectly rejected.

  ```
  val 'a x = let exception E of 'a in () end
  ```

  We have fixed the problem in our CVS.

  Thanks to Andreas Rossberg for reporting this bug.

- The x86 codegen fails to account for the possibility that a 64-bit move could interfere with itself (as simulated by 32-bit moves). We have fixed the problem in our CVS.

  Thanks to Scott Cruzen for reporting this bug.

- `NetHostDB.scan` and `NetHostDB.fromString` incorrectly raise an exception on internet addresses whose last component is a zero, e.g `0.0.0.0`. Our CVS has a patch to the Basis Library implementation.

  Thanks to Scott Cruzen for reporting this bug.

- `StreamIO.inputLine` has an off-by-one error causing it to drop the first character after a newline in some situations. Our CVS has a patch. to the Basis Library implementation.

  Thanks to Scott Cruzen for reporting this bug.

- `BinIO.getInstream` and `TextIO.getInstream` are implemented incorrectly. This also impacts the behavior of `BinIO.scanStream` and `TextIO.scanStream`. If you (directly or indirectly) realize a `TextIO.StreamIO.instream` and do not (directly or indirectly) call `TextIO.setInstream` with a derived stream, you may lose input data. We have fixed the problem in our CVS.

  Thanks to WesleyTerpstra for reporting this bug.

- `Posix.ProcEnv.setpgid` doesn't work. If you compile a program that uses it, you will get a link time error

  ```
  undefined reference to `Posix_ProcEnv_setpgid'
  ```

  The bug is due to `Posix_ProcEnv_setpgid` being omitted from the MLton runtime. We fixed the problem in our CVS by adding the following definition to `runtime/Posix/ProcEnv/ProcEnv.c`

  ```
  Int Posix_ProcEnv_setpgid (Pid p, Gid g) {
          return setpgid (p, g);
  }
  ```

  Thanks to Tom Murphy for reporting this bug.

Bugs20051202

Here are the known bugs in MLton 20051202, listed in reverse chronological order of date reported.

- Bug in the `Real<N>.fmt`, `Real<N>.fromString`, `Real<N>.scan`, and `Real<N>.toString` functions of the Basis Library implementation. These functions were using `TO_NEAREST` semantics, but should obey the current rounding mode. (Only `Real<N>.fmt StringCvt.EXACT`, `Real<N>.fromDecimal`, and `Real<N>.toDecimal` are specified to override the current rounding mode with `TO_NEAREST` semantics.)

  Thanks to Sean McLaughlin for the bug report.

  Fixed by revision `r5827`.

- Bug in the treatment of floating-point operations. Floating-point operations depend on the current rounding mode, but were being treated as pure.

  Thanks to Sean McLaughlin for the bug report.

  Fixed by revision `r5794`.

- Bug in the `Real32.toInt` function of the Basis Library implementation could lead incorrect results when applied to a `Real32.real` value numerically close to `valOf(Int.maxInt)`.

  Fixed by revision `r5764`.

- The `Socket` structure of the Basis Library implementation used `andb` rather than `orb` to unmarshal socket options (for `Socket.Ctl.get<OPT>` functions).

  Thanks to Anders Petersson for the bug report and patch.

  Fixed by revision `r5735`.

- Bug in the `Date` structure of the Basis Library implementation yielded some functions that would erroneously raise `Date` when applied to a year before 1900.

  Thanks to Joe Hurd for the bug report.

  Fixed by revision `r5732`.

- Bug in monomorphisation pass could exhibit the error `Type error:type mismatch`.

  Thanks to Vesa Karvonen for the bug report.

  Fixed by revision `r5731`.

- The `PackReal<N>.toBytes` function in the Basis Library implementation incorrectly shared (and mutated) the result vector.

  Thanks to Eric McCorkle for the bug report and patch.

  Fixed by revision `r5281`.

- Bug in elaboration of FFI forms. Using a unary FFI types (e.g., `array`, `ref`, `vector`) in places where `MLton.Pointer.t` was required would lead to an internal error `TypeError`.

  Fixed by revision `r4890`.

- The `MONO_VECTOR` signature of the Basis Library implementation incorrectly omits the specification of `find`.

  Fixed by revision `r4707`.

- The optimizer reports an internal error (`TypeError`) when an imported C function is called but not used.

  Thanks to "jq" for the bug report.

  Fixed by revision `r4690`.

- Bug in pass to flatten data structures.

  Thanks to Joe Hurd for the bug report.

  Fixed by revision `r4662`.

- The native codegen's implementation of the C-calling convention failed to widen 16-bit arguments to 32-bits.

  Fixed by revision `r4631`.

- The `PACK_REAL` structures of the Basis Library implementation used byte, rather than element, indexing.

  Fixed by revision `r4411`.

- `MLton.share` could cause a segmentation fault.

  Fixed by revision `r4400`.

- The SSA simplifier could eliminate an irredundant test.

  Fixed by revision `r4370`.

- A program with a very large number of functors could exhibit the error `ElaborateEnv.functorClosure:firstTycons`.

  Fixed by revision `r4344`.

Bugs20070826

Here are the known bugs in MLton 20070826, listed in reverse chronological order of date reported.

- Bug in the mark-compact garbage collector where the C library's `memcpy` was used to move objects during the compaction phase; this could lead to heap corruption and segmentation faults with newer versions of gcc and/or glibc, which assume that src and dst in a `memcpy` do not overlap.

  Fixed by revision `r7461`.

- Bug in elaboration of `datatype` declarations with `withtype` bindings.

  Fixed by revision `r7434`.

- Performance bug in RefFlatten optimization pass.

  Thanks to Reactive Systems for the bug report.

  Fixed by revision `r7379`.

- Performance bug in SimplifyTypes optimization pass.

  Thanks to Reactive Systems for the bug report.

  Fixed by revisions `r7377` and `r7378`.

- Bug in amd64 codegen register allocation of indirect C calls.

  Thanks to David Hansel for the bug report.

  Fixed by revision `r7368`.

- Bug in `IntInf.scan` and `IntInf.fromString` where leading spaces were only accepted if the stream had an explicit sign character.

  Thanks to David Hansel for the bug report.

  Fixed by revisions `r7227` and `r7230`.

- Bug in `IntInf.~>>` that could cause a `glibc` assertion.

  Fixed by revisions `r7083`, `r7084`, and `r7085`.

- Bug in the return type of `MLton.Process.reap`.

  Thanks to Risto Saarelma for the bug report.

  Fixed by revision `r7029`.

- Bug in `MLton.size` and `MLton.share` when tracing the current stack.

  Fixed by revisions `r6978`, `r6981`, `r6988`, `r6989`, and `r6990`.

- Bug in nested `_export`/`_import` functions.

  Fixed by revision `r6919`.

- Bug in the name mangling of `_import`-ed functions with the `stdcall` convention.

  Thanks to Lars Bergstrom for the bug report.

  Fixed by revision `r6672`.

- Bug in Windows code to page the heap to disk when unable to grow the heap to a desired size.

  Thanks to Sami Evangelista for the bug report.

  Fixed by revisions `r6600` and `r6624`.

- Bug in *NIX code to page the heap to disk when unable to grow the heap to a desired size.

  Thanks to Nicolas Bertolotti for the bug report and patch.

  Fixed by revisions `r6596` and `r6600`.

- Space-safety bug in pass to flatten refs into containing data structure.

  Thanks to Daniel Spoonhower for the bug report and initial diagnosis and patch.

  Fixed by revision r6395.

- Bug in the frontend that rejected op longvid patterns and expressions.

  Thanks to Florian Weimer for the bug report.

  Fixed by revision r6347.

- Bug in the IMPERATIVE_IO.canInput function of the Basis Library implementation.

  Thanks to Ville Laurikari for the bug report.

  Fixed by revision r6261.

- Bug in algebraic simplification of real primitives. REAL<N>.<=(x, x) is false when x is NaN.

  Fixed by revision r6242.

- Bug in the FFI visible representation of Int16.int ref (and references of other primitive types smaller than 32-bits) on big-endian platforms.

  Thanks to Dave Herman for the bug report.

  Fixed by revision r6267.

- Bug in type inference of flexible records. This would later cause the compiler to raise the TypeError exception.

  Thanks to Wesley Terpstra for the bug report.

  Fixed by revision r6229.

- Bug in cross-compilation of gdtoa library.

  Thanks to Wesley Terpstra for the bug report and patch.

  Fixed by revision r6620.

- Bug in pass to flatten refs into containing data structure.

  Thanks to Ruy Ley-Wild for the bug report.

  Fixed by revision r6191.

- Bug in the handling of weak pointers by the mark-compact garbage collector.

  Thanks to Sean McLaughlin for the bug report and Florian Weimer for the initial diagnosis.

  Fixed by revision r6183.

- Bug in the elaboration of structures with signature constraints. This would later cause the compiler to raise the TypeError exception.

  Thanks to Vesa Karvonen for the bug report.

  Fixed by revision r6046.

- Bug in the interaction of _export-ed functions and signal handlers.

  Thanks to Sean McLaughlin for the bug report.

  Fixed by revision r6013.

- Bug in the implementation of _export-ed functions using the char type, leading to a linker error.

  Thanks to Katsuhiro Ueno for the bug report.

  Fixed by revision r5999.

Bugs20100608

Here are the known bugs in MLton 20100608, listed in reverse chronological order of date reported.

- Bugs in `REAL.signBit`, `REAL.copySign`, and `REAL.toDecimal`/`REAL.fromDecimal`.

  Thanks to Phil Clayton for the bug report and examples.

  Fixed by revisions `r7571`, `r7572`, and `r7573`.

- Bug in elaboration of type variables with and without equality status.

  Thanks to Rob Simmons for the bug report and examples.

  Fixed by revision `r7565`.

- Bug in redundant SSA optimization.

  Thanks to Lars Magnusson for the bug report and example.

  Fixed by revision `r7561`.

- Bug in SSA/SSA2 shrinker that could erroneously turn a non-tail function call with a `Bug` transfer as its continuation into a tail function call.

  Thanks to Lars Bergstrom for the bug report.

  Fixed by revision `r7546`.

- Bug in translation from SSA2 to RSSA with `case` expressions over non-primitive-sized words.

  Fixed by revision `r7544`.

- Bug with SSA/SSA2 type checking of case expressions over words.

  Fixed by revision `r7542`.

- Bug with treatment of `as`-patterns, which should not allow the redefinition of constructor status.

  Thanks to Michael Norrish for the bug report.

  Fixed by revision `r7530`.

- Bug with treatment of `nan` in common subexpression elimination SSA optimization.

  Thanks to Alexandre Hamez for the bug report.

  Fixed by revision `r7503`.

- Bug in translation from SSA2 to RSSA with weak pointers.

  Thanks to Alexandre Hamez for the bug report.

  Fixed by revision `r7502`.

- Bug in amd64 codegen calling convention for varargs C calls.

  Thanks to HenryCejtin for the bug report and WesleyTerpstra for the initial diagnosis.

  Fixed by revision `r7501`.

- Bug in comment-handling in lexer for MLYacc's input language.

  Thanks to Michael Norrish for the bug report and patch.

  Fixed by revision `r7500`.

- Bug in elaboration of function clauses with different numbers of arguments that would raise an uncaught `Subscript` exception.

  Fixed by revision `r75497`.

Bugs20130715

Here are the known bugs in MLton 20130715, listed in reverse chronological order of date reported.

- Bug with simultaneous `sharing` of multiple structures.

  Fixed by commit `9cb5164f6`.

- Minor bug with exception replication.

  Fixed by commit `1c89c42f6`.

- Minor bug erroneously accepting symbolic identifiers for strid, sigid, and fctid and erroneously accepting symbolic identifiers before `.` in long identifiers.

  Fixed by commit `9a56be647`.

- Minor bug in precedence parsing of function clauses.

  Fixed by commit `1a6d25ec9`.

- Performance bug in creation of worker threads to service calls of `_export`-ed functions.

  Thanks to Bernard Berthomieu for the bug report.

  Fixed by commit `97c2bdf1d`.

- Bug in `MLton.IntInf.fromRep` that could yield values that violate the `IntInf` representation invariants.

  Thanks to Rob Simmons for the bug report.

  Fixed by commit `3add91eda`.

- Bug in equality status of some arrays, vectors, and slices in Basis Library implementation.

  Fixed by commit `a7ed9cbf1`.

Bugs20180207

Here are the known bugs in MLton 20180207, listed in reverse chronological order of date reported.

CallGraph

For easier visualization of profiling data, `mlprof` can create a call graph of the program in dot format, from which you can use the graphviz software package to create a PostScript or PNG graph. For example,

```
mlprof -call-graph foo.dot foo mlmon.out
```

will create `foo.dot` with a complete call graph. For each source function, there will be one node in the graph that contains the function name (and source position with `-show-line true`), as well as the percentage of ticks. If you want to create a call graph for your program without any profiling data, you can simply call `mlprof` without any `mlmon.out` files, as in

```
mlprof -call-graph foo.dot foo
```

Because SML has higher-order functions, the call graph is is dependent on MLton's analysis of which functions call each other. This analysis depends on many implementation details and might display spurious edges that a human could conclude are impossible. However, in practice, the call graphs tend to be very accurate.

Because call graphs can get big, `mlprof` provides the `-keep` option to specify the nodes that you would like to see. This option also controls which functions appear in the table that `mlprof` prints. The argument to `-keep` is an expression describing a set of source functions (i.e. graph nodes). The expression *e* should be of the following form.

- `all`
- `"`*`s`*`"`
- `(and` *`e`* `...)`
- `(from` *`e`*`)`
- `(not` *`e`*`)`
- `(or` *`e`*`)`
- `(pred` *`e`*`)`
- `(succ` *`e`*`)`
- `(thresh` *`x`*`)`
- `(thresh-gc` *`x`*`)`
- `(thresh-stack` *`x`*`)`
- `(to` *`e`*`)`

In the grammar, `all` denotes the set of all nodes. `"`*`s`*`"` is a regular expression denoting the set of functions whose name (followed by a space and the source position) has a prefix matching the regexp. The `and`, `not`, and `or` expressions denote intersection, complement, and union, respectively. The `pred` and `succ` expressions add the set of immediate predecessors or successors to their argument, respectively. The `from` and `to` expressions denote the set of nodes that have paths from or to the set of nodes denoted by their arguments, respectively. Finally, `thresh`, `thresh-gc`, and `thresh-stack` denote the set of nodes whose percentage of ticks, gc ticks, or stack ticks, respectively, is greater than or equal to the real number *x*.

For example, if you want to see the entire call graph for a program, you can use `-keep all` (this is the default). If you want to see all nodes reachable from function `foo` in your program, you would use `-keep '(from "foo")'`. Or, if you want to see all the functions defined in subdirectory `bar` of your project that used at least 1% of the ticks, you would use

```
-keep '(and ".*/bar/" (thresh 1.0))'
```

To see all functions with ticks above a threshold, you can also use `-thresh x`, which is an abbreviation for `-keep '(thresh x)'`. You can not use multiple `-keep` arguments or both `-keep` and `-thresh`. When you use `-keep` to display a subset of the functions, `mlprof` will add dashed edges to the call graph to indicate a path in the original call graph from one function to another.

When compiling with `-profile-stack true`, you can use `mlprof -gray true` to make the nodes darker or lighter depending on whether their stack percentage is higher or lower.

MLton's optimizer may duplicate source functions for any of a number of reasons (functor duplication, monomorphisation, polyvariance, inlining). By default, all duplicates of a function are treated as one. If you would like to treat the duplicates separately, you can use `mlprof -split` *regexp*, which will cause all duplicates of functions whose name has a prefix matching the regular expression to be treated separately. This can be especially useful for higher-order utility functions like `General.o`.

Caveats

Technically speaking, `mlprof` produces a call-stack graph rather than a call graph, because it describes the set of possible call stacks. The difference is in how tail calls are displayed. For example if `f` nontail calls `g` and `g` tail calls `h`, then the call-stack graph has edges from `f` to `g` and `f` to `h`, while the call graph has edges from `f` to `g` and `g` to `h`. That is, a tail call from `g` to `h` removes `g` from the call stack and replaces it with `h`.

CallingFromCToSML

MLton's ForeignFunctionInterface allows programs to *export* SML functions to be called from C. Suppose you would like export from SML a function of type `real * char -> int` as the C function `foo`. MLton extends the syntax of SML to allow expressions like the following:

```
_export "foo": (real * char -> int) -> unit;
```

The above expression exports a C function named `foo`, with prototype

```
Int32 foo (Real64 x0, Char x1);
```

The `_export` expression denotes a function of type `(real * char -> int) -> unit` that when called with a function `f`, arranges for the exported `foo` function to call `f` when `foo` is called. So, for example, the following exports and defines `foo`.

```
val e = _export "foo": (real * char -> int) -> unit;
val _ = e (fn (x, c) => 13 + Real.floor x + Char.ord c)
```

The general form of an `_export` expression is

```
_export "C function name" attr... : cFuncTy -> unit;
```

The type and the semicolon are not optional. As with `_import`, a sequence of attributes may follow the function name.

MLton's `-export-header` option generates a C header file with prototypes for all of the functions exported from SML. Include this header file in your C files to type check calls to functions exported from SML. This header file includes `typedefs` for the types that can be passed between SML and C.

Example

Suppose that `export.sml` is

```
val e = _export "f": (int * real * char -> char) -> unit;
val _ = e (fn (i, r, _) =>
           (print (concat ["i = ", Int.toString i,
                           "  r = ", Real.toString r, "\n"])
            ; #"g"))
val g = _import "g" public reentrant: unit -> unit;
val _ = g ()
val _ = g ()

val e = _export "f2": (Word8.word -> word array) -> unit;
val _ = e (fn w =>
           Array.tabulate (10, fn _ => Word.fromLargeWord (Word8.toLargeWord w)))
val g2 = _import "g2" public reentrant: unit -> word array;
val a = g2 ()
val _ = print (concat ["0wx", Word.toString (Array.sub (a, 0)), "\n"])

val e = _export "f3": (unit -> unit) -> unit;
val _ = e (fn () => print "hello\n");
val g3 = _import "g3" public reentrant: unit -> unit;
val _ = g3 ()

(* This example demonstrates mutual recursion between C and SML. *)
val e = _export "f4": (int -> unit) -> unit;
val g4 = _import "g4" public reentrant: int -> unit;
val _ = e (fn i => if i = 0 then () else g4 (i - 1))
val _ = g4 13

val (_, zzzSet) = _symbol "zzz" alloc: (unit -> int) * (int -> unit);
```

```
val () = zzzSet 42
val g5 = _import "g5" public: unit -> unit;
val _ = g5 ()

val _ = print "success\n"
```

Note that the the `reentrant` attribute is used for `_import`-ing the C functions that will call the `_export`-ed SML functions.

Create the header file with `-export-header`.

```
% mlton -default-ann 'allowFFI true'    \
        -export-header export.h         \
        -stop tc                        \
        export.sml
```

`export.h` now contains the following C prototypes.

```
Int8 f (Int32 x0, Real64 x1, Int8 x2);
Pointer f2 (Word8 x0);
void f3 ();
void f4 (Int32 x0);
extern Int32 zzz;
```

Use `export.h` in a C program, `ffi-export.c`, as follows.

```
#include <stdio.h>
#include "export.h"

/* Functions in C are by default PUBLIC symbols */
void g () {
        Char8 c;

        fprintf (stderr, "g starting\n");
        c = f (13, 17.15, 'a');
        fprintf (stderr, "g done  char = %c\n", c);
}

Pointer g2 () {
        Pointer res;
        fprintf (stderr, "g2 starting\n");
        res = f2 (0xFF);
        fprintf (stderr, "g2 done\n");
        return res;
}

void g3 () {
        fprintf (stderr, "g3 starting\n");
        f3 ();
        fprintf (stderr, "g3 done\n");
}

void g4 (Int32 i) {
        fprintf (stderr, "g4 (%d)\n", i);
        f4 (i);
}

void g5 () {
        fprintf (stderr, "g5 ()\n");
        fprintf (stderr, "zzz = %i\n", zzz);
        fprintf (stderr, "g5 done\n");
}
```

Compile `ffi-export.c` and `export.sml`.

```
% gcc -c ffi-export.c
% mlton -default-ann 'allowFFI true' \
         export.sml ffi-export.o
```

Finally, run `export`.

```
% ./export
g starting
...
g4 (0)
success
```

Download

- `export.sml`
- `ffi-export.c`

CallingFromSMLToC

MLton's ForeignFunctionInterface allows an SML program to *import* C functions. Suppose you would like to import from C a function with the following prototype:

```
int foo (double d, char c);
```

MLton extends the syntax of SML to allow expressions like the following:

```
_import "foo": real * char -> int;
```

This expression denotes a function of type `real * char -> int` whose behavior is implemented by calling the C function whose name is `foo`. Thinking in terms of C, imagine that there are C variables `d` of type `double`, `c` of type `unsigned char`, and `i` of type `int`. Then, the C statement `i =foo (d, c)` is executed and `i` is returned.

The general form of an `_import` expression is:

```
_import "C function name" attr... : cFuncTy;
```

The type and the semicolon are not optional.

The function name is followed by a (possibly empty) sequence of attributes, analogous to C `__attribute__` specifiers.

Example

`import.sml` imports the C function `ffi` and the C variable `FFI_INT` as follows.

```
(* main.sml *)

(* Declare ffi to be implemented by calling the C function ffi. *)
val ffi = _import "ffi" public: real array * int * int ref * char ref * int -> char;
open Array

val size = 10
val a = tabulate (size, fn i => real i)
val ri = ref 0
val rc = ref #"0"
val n = 17

(* Call the C function *)
val c = ffi (a, Array.length a, ri, rc, n)

(* FFI_INT is declared as public in ffi-import.c *)
val (nGet, nSet) = _symbol "FFI_INT" public: (unit -> int) * (int -> unit);

val _ = print (concat [Int.toString (nGet ()), "\n"])

val _ =
   print (if c = #"c" andalso !ri = 45 andalso !rc = c
             then "success\n"
          else "fail\n")
```

`ffi-import.c` is

```
#include "export.h"

Int32 FFI_INT = 13;
Word32 FFI_WORD = 0xFF;
Bool FFI_BOOL = 1;
Real64 FFI_REAL = 3.14159;
```

```
Char8 ffi (Pointer a1, Int32 a1len, Pointer a2, Pointer a3, Int32 n) {
        double *ds = (double*)a1;
        int *pi = (int*)a2;
        char *pc = (char*)a3;
        int i;
        double sum;

        sum = 0.0;
        for (i = 0; i < a1len; ++i) {
                sum += ds[i];
                ds[i] += n;
        }
        *pi = (int)sum;
        *pc = 'c';
        return 'c';
}
```

Compile and run the program.

```
% mlton -default-ann 'allowFFI true' -export-header export.h  import.sml ffi-import.c
% ./import
13
success
```

Download

- `import.sml`
- `ffi-import.c`

Next Steps

- CallingFromSMLToCFunctionPointer

CallingFromSMLToCFunctionPointer

Just as MLton can directly call C functions, it is possible to make indirect function calls; that is, function calls through a function pointer. MLton extends the syntax of SML to allow expressions like the following:

```
_import * : MLton.Pointer.t -> real * char -> int;
```

This expression denotes a function of type

```
MLton.Pointer.t -> real * char -> int
```

whose behavior is implemented by calling the C function at the address denoted by the `MLton.Pointer.t` argument, and supplying the C function two arguments, a `double` and an `int`. The C function pointer may be obtained, for example, by the dynamic linking loader (`dlopen`, `dlsym`, . . .).

The general form of an indirect `_import` expression is:

```
_import * attr... : cPtrTy -> cFuncTy;
```

The type and the semicolon are not optional.

Example

This example uses `dlopen` and friends (imported using normal `_import`) to dynamically load the math library (`libm`) and call the `cos` function. Suppose `iimport.sml` contains the following.

```
signature DYN_LINK =
   sig
      type hndl
      type mode
      type fptr

      val dlopen : string * mode -> hndl
      val dlsym : hndl * string -> fptr
      val dlclose : hndl -> unit

      val RTLD_LAZY : mode
      val RTLD_NOW : mode
   end

structure DynLink :> DYN_LINK =
   struct
      type hndl = MLton.Pointer.t
      type mode = Word32.word
      type fptr = MLton.Pointer.t

      (* These symbols come from a system libray, so the default import scope
       * of external is correct.
       *)
      val dlopen =
         _import "dlopen" : string * mode -> hndl;
      val dlerror =
         _import "dlerror": unit -> MLton.Pointer.t;
      val dlsym =
         _import "dlsym" : hndl * string -> fptr;
      val dlclose =
         _import "dlclose" : hndl -> Int32.int;

      val RTLD_LAZY = 0wx00001 (* Lazy function call binding.  *)
      val RTLD_NOW  = 0wx00002 (* Immediate function call binding.  *)
```

```
   val dlerror = fn () =>
      let
         val addr = dlerror ()
      in
         if addr = MLton.Pointer.null
            then NONE
            else let
                    fun loop (index, cs) =
                       let
                          val w = MLton.Pointer.getWord8 (addr, index)
                          val c = Byte.byteToChar w
                       in
                          if c = #"\000"
                             then SOME (implode (rev cs))
                             else loop (index + 1, c::cs)
                       end
                 in
                    loop (0, [])
                 end
      end

   val dlopen = fn (filename, mode) =>
      let
         val filename = filename ^ "\000"
         val hndl = dlopen (filename, mode)
      in
         if hndl = MLton.Pointer.null
            then raise Fail (case dlerror () of
                               NONE => "???"
                             | SOME s => s)
            else hndl
      end

   val dlsym = fn (hndl, symbol) =>
      let
         val symbol = symbol ^ "\000"
         val fptr = dlsym (hndl, symbol)
      in
         case dlerror () of
            NONE => fptr
          | SOME s => raise Fail s
      end

   val dlclose = fn hndl =>
      if MLton.Platform.OS.host = MLton.Platform.OS.Darwin
         then () (* Darwin reports the following error message if you
                  * try to close a dynamic library.
                  *   "dynamic libraries cannot be closed"
                  * So, we disable dlclose on Darwin.
                  *)
      else
         let
            val res = dlclose hndl
         in
            if res = 0
               then ()
            else raise Fail (case dlerror () of
                               NONE => "???"
                             | SOME s => s)
         end
end
```

```
val dll =
   let
      open MLton.Platform.OS
   in
      case host of
         Cygwin => "cygwin1.dll"
       | Darwin => "libm.dylib"
       | _ => "libm.so"
   end

val hndl = DynLink.dlopen (dll, DynLink.RTLD_LAZY)

local
   val double_to_double =
      _import * : DynLink.fptr -> real -> real;
   val cos_fptr = DynLink.dlsym (hndl, "cos")
in
   val cos = double_to_double cos_fptr
end

val _ = print (concat ["    Math.cos(2.0) = ", Real.toString (Math.cos 2.0), "\n",
                       "libm.so::cos(2.0) = ", Real.toString (cos 2.0), "\n"])

val _ = DynLink.dlclose hndl
```

Compile and run `iimport.sml`.

```
% mlton -default-ann 'allowFFI true'     \
        -target-link-opt linux -ldl      \
        -target-link-opt solaris -ldl    \
         iimport.sml
% iimport
    Math.cos(2.0) = ~0.416146836547
libm.so::cos(2.0) = ~0.416146836547
```

This example also shows the `-target-link-opt` option, which uses the switch when linking only when on the specified platform. Compile with `-verbose 1` to see in more detail what's being passed to `gcc`.

Download

- `iimport.sml`

CCodegen

The CCodegen is a code generator that translates the Machine IntermediateLanguage to C, which is further optimized and compiled to native object code by `gcc` (or another C compiler).

Implementation

- `c-codegen.sig`
- `c-codegen.fun`

Details and Notes

The CCodegen is the original code generator for MLton.

Changelog

- CHANGELOG.adoc

```
= CHANGELOG

== Version 20180206

Here are the changes from version 20130715 to version 20180206.

=== Summary

* Compiler.
  ** Added an experimental LLVM codegen (`-codegen llvm`); requires LLVM tools
  (`llvm-as`, `opt`, `llc`) version &ge; 3.7.
  ** Made many substantial cosmetic improvements to front-end diagnostic
  messages, especially with respect to source location regions, type inference
  for `fun` and `val rec` declarations, signature constraints applied to a
  structure, `sharing type` specifications and `where type` signature
  expressions, type constructor or type variable escaping scope, and
  nonexhaustive pattern matching.
  ** Fixed minor bugs with exception replication, precedence parsing of function
  clauses, and simultaneous `sharing` of multiple structures.
  ** Made compilation deterministic (eliminate output executable name from
  compile-time specified `@MLton` runtime arguments; deterministically generate
  magic constant for executable).
  ** Updated `-show-basis` (recursively expand structures in environments,
  displaying components with long identifiers; append `(* @ region *)`
  annotations to items shown in environment).
  ** Forced amd64 codegen to generate PIC on amd64-linux targets.
* Runtime.
  ** Added `gc-summary-file file` runtime option.
  ** Reorganized runtime support for `IntInf` operations so that programs that
  do not use `IntInf` compile to executables with no residual dependency on GMP.
  ** Changed heap representation to store forwarding pointer for an object in
  the object header (rather than in the object data and setting the header to a
  sentinel value).
* Language.
  ** Added support for selected SuccessorML features; see
  http://mlton.org/SuccessorML for details.
  ** Added `(*#showBasis "file" *)` directive; see
  http://mlton.org/ShowBasisDirective for details.
  ** FFI:
    *** Added `pure`, `impure`, and `reentrant` attributes to `_import`.  An
    unattributed `_import` is treated as `impure`.  A `pure` `_import` may be
    subject to more aggressive optimizations (common subexpression elimination,
    dead-code elimination).  An `_import`-ed C function that (directly or
    indirectly) calls an `_export`-ed SML function should be attributed
    `reentrant`.
  ** ML Basis annotations.
    *** Added `allowSuccessorML {false|true}` to enable all SuccessorML features
    and other annotations to enable specific SuccessorML features; see
    http://mlton.org/SuccessorML for details.
    *** Split `nonexhaustiveMatch {warn|error|igore}` and `redundantMatch
    {warn|error|ignore}` into `nonexhaustiveMatch` and `redundantMatch`
    (controls diagnostics for `case` expressions, `fn` expressions, and `fun`
    declarations (which may raise `Match` on failure)) and `nonexhaustiveBind`
    and `redundantBind` (controls diagnostics for `val` declarations (which may
    raise `Bind` on failure)).
    *** Added `valrecConstr {warn|error|ignore}` to report when a `val rec` (or
    `fun`) declaration redefines an identifier that previously had constructor
```

```
    status.
* Libraries.
  ** Basis Library.
    *** Improved performance of `Array.copy`, `Array.copyVec`, `Vector.append`,
    `String.^`, `String.concat`, `String.concatWith`, and other related
    functions by using `memmove` rather than element-by-element constructions.
  ** `Unsafe` structure.
    *** Added unsafe operations for array uninitialization and raw arrays; see
    https://github.com/MLton/mlton/pull/207 for details.
  ** Other libraries.
    *** Updated: ckit library, MLLPT library, MLRISC library, SML/NJ library
* Tools.
  ** mlnlffigen
    *** Updated to warn and skip (rather than abort) when encountering functions
    with `struct`/`union` argument or return type.

=== Details

* 2018-02-6
  ** Remove ancient and unused `cmcat` tool.

* 2018-02-03
  ** Upgrade `gdtoa.tgz`.

* 2018-02-02
  ** Remove docs from `all` target of `./Makefile`; this eliminates the
  `all-no-docs` target (which was frequently used in favor of `all`).

* 2018-01-31
  ** Use C compiler with `-std=gnu11` (rather than `-std=gnu99`).
  ** Revert rudimentary support for `./configure`; the support was so minimal
  that it seems unhelpful to pretend that there are exhaustive compatibility
  checks being performed.  All of the basic configuration can be accomplished
  with simple `make` variable definitions.

* 2018-01-25
  ** Remove (expert, undocumented) `-debug-format` option; the same effect can
  be achieved with `-as-opt` and `-cc-opt`.
  ** Propagate C compiler from `./configure` to `mlton` script.

* 2018-01-24
  ** Extend `-target-*-opt` options to support `arch-os` pairs.
  ** Remove `./package/rpm/*` and corresponding targets in `./Makefile`;
  upstream MLton has not produced RPMs for years.

* 2018-01-24
  ** Slightly improve performance of `Vector.concat` and
  `String.{concat,concatWith,tokens,fields}` by avoiding `List.map`-s.

* 2018-01-23
  ** Restore, but deprecate, `-drop-pass` compile-time expert option.

* 2018-01-19
  ** Update SML/NJ libraries to SML/NJ 110.82.

* 2017-12-29
  ** Add support for `(*#showBasis "file" *)` directives.  This feature is
  meant to facilitate auto-completion via
  https://github.com/MatthewFluet/company-mlton[`company-mlton`] and similar
  tools.

* 2017-12-20
```

```
  ** Update performance comparison on website.  Thanks to Curtis Dunham for the
  pull request.

* 2017-12-17
  ** Updates to `-show-basis`:
    *** `-show-basis-flat`: Recursively expand structures in environments,
    displaying components with long identifiers.
    *** `-show-basis-def`: Appends `(* @ region *)` annotations to items shown
    in environment.
    *** `-show-basis-compact`: Tries to optimize vertical space (at the expense
    of long lines).

* 2017-12-11
  ** Drop `_BSD_SOURCE` and `_POSIX_C_SOURCE` feature macros in
  `./runtime/cenv.h`.

* 2017-12-10
  ** Add a `Dockerfile` to build/test MLton.  Thanks to Richard Laughlin for the
  pull request.

* 2017-12-06
  ** Remove `$PREFIX` and `$prefix` from top-level `Makefile.in`; use
  `./configure --prefix path`.  Thanks to Richard Laughlin for the pull
  request.

* 2017-12-03
  ** Fix heap invariant predicates.

* 2017-11-15
  ** Eliminate the use of (some) global mutable state for signal handling.

* 2017-11-14
  ** Store forwarding pointer for an object in the object header (rather than in
  the object data and setting the header to a sentinel value).

* 2017-11-02
  ** Updates to stack management in backend:
    *** Improve `Allocation.Stack.get`.
    *** Do not force `Cont` block arguments to stack.

* 2017-10-30
  ** In `signature SSA_TO_RSSA_STRUCTS` share by `Rssa.Atoms = Ssa.Atoms`.  This
  is the idiom used elsewhere in the compiler, rather than sharing individual
  sub-structures of `Atoms`.
  ** Minor updates to `DirectedGraph` and `Tree` in MLton library.

* 2017-10-23
  ** Add `-seed-rand w` compile-time option, to seed the pseudo-random number
  generator.
  ** Add a new MachineShuffle pass (disabled by default) that shuffles the
  collection of chunks within the program and shuffles the collection of blocks
  within a chunk.  With the `-seed-rand w` compile-time option, can be used to
  generate executables with distinct code placements.

* 2017-10-23
  ** Use a relative path in the `mlton` script, rather than an absolute path.
  The absolute path needed to be set to the intended installation directory,
  which made it difficult to install a binary release in a local directory.
  Undertaken by Maksim Yegorov at RIT supported by NSF CISE Research
  Infrastructure (CRI) award.

* 2017-10-21
```

```
  ** Add unsafe operations for array uninitialization and raw arrays.
    *** Rename `Array_uninit: SeqIndex.int -> 'a array` primitive to
    `Array_alloc: SeqIndex.int -> 'a array`.
    *** Add `Array_uninit: 'a array * SeqIndex.int -> unit` primitive to set all
    objptrs in the element at the given index to a bogus non-objptr value
    (`0wx1`).  One motivation for this primitive is to support space-efficient
    polymorphic resizeable arrays.  When shrinking a resizeable array, we would
    like to "`NULL`" out the elements that are no longer part of the logical
    array, in order to avoid a (logical) space leak.
    *** Add `Array_uninitIsNop: 'a array -> bool` primitive to answer if the
    `Array_uninit` primitive applied to the same array would be a nop (i.e., if
    the array has no objptrs in the elements).  This can be used to skip a
    bulk-`Array_uninit` loop when it is known that the `Array_uninit` operations
    would be nops.
    *** Add `Array_allocRaw: SeqIndex.int -> 'a array` primitive to allocate an
    array, but with a header that indicates that the array has no objptrs.  Add
    `Array_toArray: 'a array -> 'a array` primitive to update the header of an
    `Array_allocRaw` allocated array to reveal the objptrs.  One motiviation for
    this primitive is that, in a parallel setting, the uninitialization of an
    array can be a sequential bottleneck.  The `Array_allocRaw` is a constant
    time operation and the subsequent `Array_uninit` operations can be performed
    in parallel.
    *** Extend `structure Unsafe.Array` with additional operations.  See
    `./basis-library/sml-nj/unsafe.sig`.

* 2017-10-20
  ** Introduce ShareZeroVec SSA optimization to share zero-length vectors after
  coercion-based optimizations.  Undertaken by Maksim Yegorov at RIT supported
  by NSF CISE Research Infrastructure (CRI) award.

* 2017-10-18
  ** New canonicalization strategy for CommonSubexp SSA optimization.
  Previously, the canonicalization of commutative arithmetic primitives was
  sensitive to variable hashes (created by an unseeded pseudo-random number
  generator); now, the canonicalization of commutative arithmetic primitives is
  sensitive to relative definition order of variables.

* 2017-10-12
  ** Fix bug in runtime argument option parsing.

* 2017-10-05
  ** Many updates and improvements to diagnostic messages.  See
  https://github.com/MLton/mlton/pull/195 for details.

* 2017-09-27
  ** Add rudimentary support for `./configure`; in particular, support
  `--with-gmp-lib` and `--with-gmp-include` to set location of GMP and
  `--prefix` to specify an install prefix.  Undertaken by Maksim Yegorov at RIT
  supported by NSF CISE Research Infrastructure (CRI) award.

* 2017-08-21
  ** Introduce `Array_copyArray: 'a array * SeqIndex.int * 'a array *
  SeqIndex.int * SeqIndex.int -> unit` and `Array_copyVector: 'a array *
  SeqIndex.int * 'a vector * SeqIndex.int * SeqIndex.int -> unit` primitives
  which are used to implement a number of array and vector construction
  functions, particularly `append`, `concat`, and `concatWith`.  The primitives
  compile to `memmove` operations, which (significantly) outperforms MLton's
  element-by-element construction for large sequences.  Undertaken by Bryan Camp
  at RIT supported by NSF CISE Research Infrastructure (CRI) award.

* 2017-07-25
  ** Force PIC generation on amd64-linux targets.  Thanks to Kuen-Bang Hou
```

```
  (Favonia) for the pull request.

* 2017-07-11
  ** Generalize the `subWord` primitives to
+
----
      | WordArray_subWord of {seqSize:WordSize.t, eleSize: WordSize.t}
      | WordArray_updateWord of {seqSize: WordSize.t, eleSize: WordSize.t}
      | WordVector_subWord of {seqSize: WordSize.t, eleSize: WordSize.t}
----
+
Undertaken by Bryan Camp at RIT supported by NSF CISE Research Infrastructure
(CRI) award.

* 2017-07-11
  ** Add a parser combinator library (`structure StreamParser`) to the MLton
  Library.  Undertaken by Jason Carr at RIT supported by NSF CISE Research
  Infrastructure (CRI) award.
  ** Add a parser for the SXML IR (`structure ParseSxml`).  Undertaken by Jason
  Carr at RIT supported by NSF CISE Research Infrastructure (CRI) award.
  ** Allow compilation to start with a `.sxml` file.  Undertaken by Jason Carr
  at RIT supported by NSF CISE Research Infrastructure (CRI) award.

* 2017-06-29
  ** Replace `-drop-pass regex` compile-time option with `-disable-pass regex`
  compile option and add `-enable-pass regex` compile option.  Various XML,
  SXML, SSA, SSA2, RSSA, and Machine IR optimization passes are initialized with
  a default status, which can be overriden by `-{disable,enable}-pass`.  In
  particular, it is now easy to add a work-in-progress (and potentially buggy)
  pass to the simplification pipeline with `execute = false` default status, to
  be selectively executed with `-enable-pass`.  Undertaken by Bryan Camp at RIT
  supported by NSF CISE Research Infrastructure (CRI) award.
  ** Add LoopUnswitch and LoopUnroll SSA optimizations (undertaken by Matthew
  Surawski as an RIT CS MS Capstone Project).  Initial evaluation demonstrates
  some non-trivial performance gains, no non-trivial performance losses, and
  only minor code size increases, but currently disabled pending a more thorough
  evaluation.

* 2017-05-23
  ** Expand the set of MLB annotations:
    *** `nonexhaustiveBind`, `nonexhaustiveExnBind`, `redundantBind`: controls
    diagnostics for `val` declarations (which may raise `Bind` on failure).
    *** `nonexhaustiveMatch`, `nonexhaustiveExnMatch`, `redundantMatch`:
    controls diagnostics for `case` expressions, `fn` expressions, and `fun`
    declarations (which may raise `Match` on failure).
    *** `nonexhaustiveRaise`, `nonexhaustiveExnRaise`, `redundantRaise`:
    controls diagnostics for `handle` expressions (which implicitly re-raise on
    failure).  Note that `nonexhaustiveRaise` and `nonexhaustiveExnRaise`
    default to `ignore`.  The combination of `nonexhaustiveRaise warn` and
    `nonexhaustiveExnRaise ignore` can be useful for finding handlers that
    handle some, but not all, values of an exception variant.
  ** Make a number of improvements to diagnostic messages:
    *** Display nonexhaustive exception patterns as `_ : exn`, rather than
    `e`.
    *** Normalize nonexhaustive patterns by sorting (e.g., by `ConApp` name).
    *** Report complete enumeration of unhandled constants, rather than a single
    example.
    *** Report nonexhaustive patterns of record type as records, rather than as
    tuples.

* 2017-04-20
  ** Updates to SSA, SSA2, and RSSA IR support infrastructure
```

```
    *** Display more context when reporting SSA and SSA2 IR type errors.
    *** Add `-layout-width n` compile expert option to control the target width
    for the pretty printer.
    *** Make cosmetic improvments to SSA and SSA2 IR display (uses of global
    variables bound to small constants and conapps are commented with the
    corresponding value; include loop forest for functions with `-keep dot`).
    *** Improve RSSA constant folding and copy propagation.
    *** Limit Machine IR `Globals` to variables used outside of the `main`
    function.

* 2017-04-15
  ** Add `gc-summary-file file` runtime option.

* 2017-04-15
  ** Rename and add `smlnj-mlton-x{2,4,8,16}` top-level `Makefile` targets.
  ** Update SML/NJ librarys to SML/NJ 110.80 (making use of supported
  SuccessorML features).
  ** Not support for SML/NJ extensions via SuccessorML MLB annotations on
  website.

* 2017-04-14
  ** Add support for vector expressions (`#[e1, e2, ..., en]`) and vector
  patterns (`#[p1, p2, ..., pn]`) and add `Vector_vector` n-ary primitive.
  Initial support for vector expressions and the `Vector_vector` primitive were
  undertaken by Krishna Ravikumar as an RIT CS MS Capstone Project.

* 2017-03-29
  ** Update DOS eol handling and tweak error messages in lexer.

* 2017-03-27
  ** Correct off-by-one error in column numbers.  Thanks to Jacob Zimmerman for
  the error report and pull request.

* 2017-03-15
  ** Updates to SuccessorML support:
    *** Add an `allowSuccessorML {false|true}` MLB annotation to enable all
    Successor ML features with a single annotation.
    *** Fix parsing of numeric labels to only accept an INT token that does not
    begin with 0, is not an extended literal, is not negative, and is decimal.
    *** Drop the alternate word prefixes (`0xw` and `0bw`).
    *** Unconditionally allow line comments in MLB files.
    *** Allow UTF-8 byte sequences in text constants.
    *** Refactor `ml.lex` and `mlb.lex` to be more maintainable.
    *** Rename `allowRecPunning` annotation to `allowRecordPunExps`.

* 2017-02-27
  ** Update ML-Yacc examples (`calc`, `fol`, `pascal`) to comply with MLton
  build process.  Thanks to Hai Nguyen Van for the pull request.

* 2017-01-25
  ** Update PortingMLton documentation and `./bin/add-cross` script.  Thanks to
  Daniel Moerner for the pull request.

* 2016-09-29
  ** Constant fold `CPointer_equal(NULL, NULL)` to `true`.

* 2016-09-29
  ** Introduce `NEEDS_SIGALTSTACK_EXEC` config in runtime system.

* 2016-09-27
  ** Construct a devel build version string from last commit time and last
  commit hash.
```

```
  ** Omit build date and build node from version banner; makes self-compiles
  deterministic.
  ** Remove `upgrade-basis.sml` from build.  The generated `upgrade-basis.sml`
  was introduced to handle incompatibilities in the Basis Library provided by an
  old version of MLton and the Basis Library assumed by the current sources.
  However, there are no incompatibilities with MLton 20130715, MLton 20100608,
  or MLton 20070826.  Nonetheless, the feature testing performed by
  `./bin/upgrade-basis` to generate `upgrade-basis.sml` is time consuming,
  especially when trying to simply type check the compiler sources.

* 2016-06-20
  ** Do not `gzip` man pages on OpenBSD.  Thanks to Alexander Abushkevich for
  the pull request.

* 2016-06-20
  ** Generate position independent code for OpenBSD.  Thanks to Alexander
  Abushkevich for the pull request.

* 2016-06-20
  ** Fix profiling for amd64-openbsd and x86-openbsd.  Thanks to Alexander
  Abushkevich for the pull request.

* 2016-04-06
  ** Update SML/NJ librarys to SML/NJ 110.79.

* 2016-03-22
  ** Update LLVM codegen to support (and require) >= llvm-3.7.  Thanks to Eugene
  Akentyev for the pull request.

* 2016-02-26
  ** Configure GMP location via `Makefile`.

* 2016-01-10
  ** Fix typo in `mlb-formal.tex`.  Thanks to Jon Sterling for the pull request.

* 2015-11-10
  ** Update SML/NJ librarys to SML/NJ 110.78.  Use `allowOrPats` and
  `allowSigWithtype` to minimize diffs.

* 2015-10-20
  ** Fix elaboration of `withtype` in signature.

* 2015-10-06
  ** Add support for setting CM anchor bindings in `cm2mlb` tool.

* 2015-10-06
  ** Fix non-exhaustive match warnings with or-patterns.  Thanks to Rob Simmons
  for the bug report.
  ** Distinguish between partial and fully redundant matches.
  ** Report partial redundancy in `val` declarations.
  ** Lower precedence of or-patterns in parser.
  ** Make a variety of cosmetic improvements to non-exhaustive and redundant
  error/warning messages, primarily to be consistent in formatting between
  quoted AST and generated messages.

* 2015-07-10
  ** Extend support for arm64 (aarch64).  Thanks to Edmund Evans for the patch.

* 2015-06-22
  ** Introduce `valrecConstr {warn|error|ignore}` MLB annotation to report when
  a `val rec` (or `fun`) declaration redefines an identifier that previously had
  constructor status.
```

```
* 2015-06-19
  ** Add support for selected SuccessorML features (undertaken by Kevin Bradley
  as an RIT CS MS Capstone Project).
    *** `do`-declarations (`allowDoDecls`)
    *** extended literals (`allowExtendedLiterals`)
    *** line comments (`allowLineComments`)
    *** optional leading bar in matches, fun decls, and datatype decls
    (`allowOptBar`)
    *** optional trailing semicolon in sequence expressions (`allowOptSemicolon`)
    *** or patterns (`allowOrPats`)
    *** record expression punning (`allowRecPunning`)
    *** withtype in signatures (`allowSigWithtype`)

* 2015-06-10
  ** Hide equality status of poly (and mono) vector and array slices.
  ** Hide type equality of mono and poly `Word8.word` arrays and vectors.

* 2015-06-08
  ** Added `reentrant` attribute to `_import`.  An `_import`-ed C function that
  (directly or indirectly) calls an `_export`-ed SML function should be
  attributed `reentrant`.

* 2015-06-08
  ** Make compilation deterministic:
    *** Eliminate output executable name from compile-time specified `@MLton`
    arguments.
    *** Deterministically generate magic constant for executable.

* 2015-06-08
  ** Add `-keep ast` compile option.  Undertaken by Ross Bayer at RIT supported
  by NSF CISE Research Infrastructure (CRI) award.

* 2015-06-02
  ** Updates to Debian packaging.  Thanks to Christopher Cramer for the pull
  request.

* 2015-03-30
  ** Use `LANG=en_us` when computing version and build date.  Thanks to Eugene
  Akentyev for the pull request.

* 2015-02-17
  ** Update `mlnlffigen` to warn and skip functions with `struct`/`union`
  arguments.  Thanks to Armando Doval for the pull request.

* 2014-12-22
  ** Move pervasive constructs from `./mlton/ast` to `./mlton/atoms`, so that
  `./mlton/ast/sources.mlb` depends on `./mlton/atoms/sources.mlb` (and not the
  other way around).  Undertaken by Vedant Raiththa at RIT supported by NSF CISE
  Research Infrastructure (CRI) award.

* 2014-12-17
  ** Cache a worker thread to service calls of `_export`-ed functions.  Thanks
  to Bernard Berthomieu for the bug report.

* 2014-12-02
  ** Post-process generated front-end files for compatibility with SML/NJ's
  recent `ml-lex` and `ml-yacc` tools that generate log identifiers rather than
  unqualified (top-level environment) identifiers.
  ** Corrected documentation for SML/NJ `Makefile` target and fixed
  `bootstrap-nj` target.  Thanks to Daniel Rosenwasser for the pull request.
```

```
* 2014-11-21
  ** Reorganized runtime support for `IntInf` operations so that programs that
  do not use `IntInf` compile to executables with no residual dependency on GMP.
  ** Fixed bug in `MLton.IntInf.fromRep` that could yield values that violate
  the `IntInf` representation invariants. Thanks to Rob Simmons for the bug
  report.

* 2014-10-24
  ** Added `pure` and `impure` attributes to `_import`.  An unattributed
  `_import` is treated as `impure`.  A `pure` `_import` may be subject to more
  aggressive optimizations (common subexpression elimination, dead-code
  elimination).  Undertaken by Vedant Raiththa at RIT supported by NSF CISE
  Research Infrastructure (CRI) award.

* 2014-10-22
  ** Various updates to treatment of `IntInf` constants in the compiler.
    *** Recognize both `Big` and `Small` representations of `IntInf`-s.
    *** Translate `IntInf` consts to `Big` and `Small` representations in
    conversion from SSA to RSSA. This is consistent with the treatment of other
    `IntInf` operations in the conversion. After the conversion, `IntInf` is no
    longer treated as a primitive.
    *** Remove `initIntInfs` from program initialization.
    *** Constant fold `IntInf_toVector` and `WordVector_toIntInf` primitives.

* 2014-10-20
  ** Various updates to `structure WordXVector` in compiler proper.
    *** Update the `WordXVector.layout` function. If the `elementSize` is
   `WordX.word8` and more than 90% of the characters satisfy `Char.isGraph
   orelse Char.isSpace`, then display as an SML string constant (with
   non-printable characters SML-escaped). Otherwise, display as an SML/NJ-style
   `#[0x0, 0xF]` vector literal.
    *** Update initialization of `static struct GC_vectorInit vectorInits[]`
   constants in runtime. If the `WordXVector`'s (primitive) `elementSize` is
   `WordSize.W8`, then emit a C-escaped string constant. Otherwise, emit a
   C-array initialization.

* 2014-08-15
  ** More updates to benchmark infrastructure.
    *** Make `update-counts.sh` script more robust.
    *** Update `hamlet.sml` benchmark program to close input file after each
    loop.
    *** Update `fft.sml` benchmark program to only invoke `test` function with
    power-of-2 arguments.
    *** Update `model-elimination.sml` benchmark program to iterate `main ()`
    according to `doit` size parameter.

* 2014-08-11
  ** Include `winsock2.h` before `windows.h` in MinGW port.  Thanks to Shu-Hung
  You for the pull request.

* 2014-07-31
  ** Refactor array and vector implementation in Basis Library into a primitive
  implementation (using `SeqInt.int` for indexing) and a wrapper implementation
  (using the default `Int.int` for indexing).  Thanks to Rob Simmons for the
  pull request.
  ** Correct description of `MLton.{Vector,Array}.unfoldi` on website.  Thanks
  to Rob Simmons for the pull request.

* 2014-07-14
  ** Updates to benchmark infrastructure.
    *** Add `even-odd.sml` benchmark that exercises mutual tail recursion.
    *** Add `update-counts.sh` script to calculate appropriate benchmark
```

```
    iteration counts and update benchmark iteration counts so that all
    benchmarks run for at least 30 seconds.
    *** Updates to benchmark driver program.

* 2014-07-07
  ** Change `./basis-library/integer/int-inf.sml` to reduce dependency on
  GMP-specific details of `./basis-library/integer/int-inf0.sml`.  Thanks to Rob
  Simmons for the pull request.
  ** Correct type and description of `MLton.IntInf.fromRep` on website.  Thanks
  to Rob Simmons for the pull request.

* 2014-07-01
  ** Add experimental LLVM codegen (undertaken by Brian Leibig as an RIT CS MS
  Project).

* 2014-06-09
  ** Update `CallingFromSMLToC` page on website.  Thanks to Bikal Gurung for the
  pull request.

* 2014-03-18
  ** Updates for MinGW port.

* 2014-02-07
  ** Update AsciiDoc sources for website.

* 2013-10-31
  ** Various updates to website.  Thanks to Mauricio C Antunes for the pull
  request.
    *** Add Tofte's tutorial and Rossberg's grammar.
    *** Fix links to implementations.

* 2013-10-10
  ** Update links from `References` page on website.  Thanks to Mauricio C
  Antunes for the pull request.

* 2013-09-02
  ** Fix example for `Lazy` page on website.  Thanks to Daniel Rosenwasser for
  the pull request.

== Version 20130715

Here are the changes from version 20100608 to version 20130715.

=== Summary

* Compiler.
  ** Cosmetic improvements to type-error messages.
  ** Removed features:
    *** Bytecode codegen: The bytecode codegen had not seen significant use and
    it was not well understood by any of the active developers.
    *** Support for `.cm` files as input: The ML Basis system provides much
    better infrastructure for "programming in the very large" than the (very)
    limited support for CM.  The `cm2mlb` tool (available in the source
    distribution) can be used to convert CM projects to MLB projects, preserving
    the CM scoping of module identifiers.
  ** Bug fixes: see changelog
* Runtime.
  ** Bug fixes: see changelog
* Language.
  ** Interpret `(*#line line:col "file" *)` directives as relative
  file names.
  ** ML Basis annotations.
```

```
    *** Added: `resolveScope`
* Libraries.
  ** Basis Library.
    *** Improved performance of `String.concatWith`.
    *** Use bit operations for `REAL.class` and other low-level operations.
    *** Support additional variables with `Posix.ProcEnv.sysconf`.
    *** Bug fixes: see changelog
  ** `MLton` structure.
    *** Removed: `MLton.Socket`
  ** Other libraries.
    *** Updated: ckit library, MLRISC library, SML/NJ library
    *** Added: MLLPT library
* Tools.
  ** mllex
    *** Generate `(*#line line:col "file.lex" *)` directives with simple
    (relative) file names, rather than absolute paths.
  ** mlyacc
    *** Generate `(*#line line:col "file.grm" *)` directives with simple
    (relative) file names, rather than absolute paths.
    *** Fixed bug in comment-handling in lexer.

=== Details

* 2013-07-06
  ** Update SML/NJ libraries to SML/NJ 110.76.

* 2013-06-19
  ** Upgrade `gdtoa.tgz`; fixed bug in `Real32.{fmt,toDecimal,toString}`, which
  in some cases produced too many digits

* 2013-06-18
  ** Removed `MLton.Socket` structure (deprecated in last release).

* 2013-06-10
  ** Improved performance of `String.concatWith`.

* 2013-05-22
  ** Update SML/NJ libraries to SML/NJ 110.75.

* 2013-04-30
  ** Detect PowerPC 64 architecture.

* 2012-10-09
  ** Fixed bug in elaboration that erroneously accepted the following:

      signature S = sig structure A : sig type t end
                            and B : sig type t end where type t = A.t end

* 2012-09-04
  ** Introduce an MLB annotation to control overload and flex record resolution
  scope: `resolveScope {strdec|dec|topdec|program}`.

* 2012-07-04
  ** Simplify use of `getsockopt` and `setsockopt` in Basis Library.
  ** Direct implementation of `Socket.Ctl.{getATMARK,getNREAD}` in runtime
  system, rather than indirect implementation in Basis Library via `ioctl`.
  ** Replace use of casting through a union with `memcpy` in runtime.

* 2012-06-11
  ** Use bit operations for `REAL.class` and other low-level operations.
  ** Fixed bugs in `REAL.copySign`, `REAL.signBit`, and `REAL.{to,from}Decimal`.
```

```
* 2012-06-01
  ** Cosmetic improvements to type-error messages.
  ** Fixed bug in elaboration that erroneously rejected the following:

      datatype ('a, ''a) t = T
      type ('a, ''a) u = unit

  and erroneously accepted the following:

      fun f (x: 'a) : ''a = x
      fun g (x: 'a) : ''a = if x = x then x else x

* 2012-02-24
  ** Fixed bug in redundant SSA optimization.

* 2011-06-20
  ** Support additional variables with `Posix.ProcEnv.sysconf`.

* 2011-06-17
  ** Change `mllex` and `mlyacc` to generate `#line` directives with simple file
  names, rather than absolute paths.
  ** Interpret `#line` directives as relative file names.

* 2011-06-14
  ** Fixed bug in SSA/SSA2 shrinker that could erroneously turn a non-tail
  function call with a `Bug` transfer as its continuation into a tail function
  call.

* 2011-06-11
  ** Update SML/NJ libraries to SML/NJ 110.73 and add ML-LPT library.

* 2011-06-10
  ** Fixed bug in translation from SSA2 to RSSA with case expressions over
  non-primitive-sized words.
  ** Fixed bug in SSA/SSA2 type checking of case expressions over words.

* 2011-06-04
  ** Upgrade `gdtoa.tgz`.
  ** Remove bytecode codegen.
  ** Remove support for `.cm` files as input.

* 2011-05-03
  ** Fixed a bug with the treatment of `as`-patterns, which should not allow the
  redefinition of constructor status.

* 2011-02-18
  ** Fixed bug with treatment of nan in common subexpression elimination SSA
  optimization.

* 2011-02-18
  ** Fixed bug in translation from SSA2 to RSSA with weak pointers.

* 2011-02-05
  ** Fixed bug in amd64 codegen calling convention for varargs C calls.

* 2011-01-17
  ** Fixed bug in comment-handling in lexer for `mlyacc`'s input language.

* 2010-06-22
  ** Fixed bug in elaboration of function clauses with different numbers of
  arguments that would raise an uncaught `Subscript` exception.
```

```
== Version 20100608

Here are the changes from version 20070826 to version 20100608.

=== Summary

* New platforms.
  ** ia64-hpux
  ** powerpc64-aix
* Compiler.
  ** Command-line switches.
    *** Added: `-mlb-path-var '<name> <value>'`
    *** Removed: `-keep sml`, `-stop sml`
  ** Improved constant folding of floating-point operations.
  ** Experimental: Support for compiling to a C library; see wiki documentation.
  ** Extended `-show-def-use` output to include types of variable definitions.
  ** Deprecated features (to be removed in a future release)
    *** Bytecode codegen: The bytecode codegen has not seen significant use and
    it is not well understood by any of the active developers.
    *** Support for `.cm` files as input: The ML Basis system provides much
    better infrastructure for "programming in the very large" than the (very)
    limited support for CM.  The `cm2mlb` tool (available in the source
    distribution) can be used to convert CM projects to MLB projects, preserving
    the CM scoping of module identifiers.
  ** Bug fixes: see changelog
* Runtime.
  ** `@MLton` switches.
    *** Added: `may-page-heap {false|true}`
  ** `may-page-heap`: By default, MLton will not page the heap to disk when
  unable to grow the heap to accomodate an allocation.  (Previously, this
  behavior was the default, with no means to disable, with security an
  least-surprise issues.)
  ** Bug fixes: see changelog
* Language.
  ** Allow numeric characters in ML Basis path variables.
* Libraries.
  ** Basis Library.
    *** Bug fixes: see changelog.
  ** `MLton` structure.
    *** Added: `MLton.equal`, `MLton.hash`, `MLton.Cont.isolate`,
    `MLton.GC.Statistics, `MLton.Pointer.sizeofPointer`,
    `MLton.Socket.Address.toVector`
    *** Changed:
    *** Deprecated: `MLton.Socket`
  ** `Unsafe` structure.
    *** Added versions of all of the monomorphic array and vector structures.
  ** Other libraries.
    *** Updated: ckit library, MLRISC library, SML/NJ library.
* Tools.
  ** `mllex`
    *** Eliminated top-level `type int = Int.int` in output.
    *** Include `(*#line line:col "file.lex" *)` directives in output.
    *** Added `%posint` command, to set the `yypos` type and allow the lexing of
    multi-gigabyte files.
   ** `mlnlffigen`
    *** Added command-line switches `-linkage archive` and `-linkage shared`.
    *** Deprecated command-line switch `-linkage static`.
    *** Added support for ia64 and hppa targets.
   ** `mlyacc`
    *** Eliminated top-level `type int = Int.int` in output.
    *** Include `(*#line line:col "file.grm" *)` directives in output.
```

```
=== Details

* 2010-05-12
  ** Fixed bug in the mark-compact garbage collector where the C library's
  `memcpy` was used to move objects during the compaction phase; this could lead
  to heap corruption and segmentation faults with newer versions of `gcc` and/or
  `glibc`, which assume that src and dst in a `memcpy` do not overlap.

* 2010-03-12
  ** Fixed bug in elaboration of `datatype` declarations with `withtype`
  bindings.

* 2009-12-11
  ** Fixed performance bug in RefFlatten SSA2 optimization.

* 2009-12-09
  ** Fixed performance bug in SimplifyTypes SSA optimization.

* 2009-12-02
  ** Fixed bug in amd64 codegen register allocation of indirect C calls.

* 2009-09-17
  ** Fixed bug in `IntInf.scan` and `IntInf.fromString` where leading spaces
  were only accepted if the stream had an explicit sign character.

* 2009-07-10
  ** Added CombineConversions SSA optimization.

* 2009-06-09
  ** Removed deprecated command line switch `-show-anns {false, true}`.

* 2009-04-18
  ** Removed command line switches `-keep sml` and `-stop sml`.  Their meaning
  was unclear with `.mlb` files; their effect with `.cm` files can be achieved
  with `-stop f`.

* 2009-04-16
  ** Fixed bug in `IntInf.~>>` that could cause a `glibc` assertion failure.

* 2009-04-01
  ** Fixed exported type of `MLton.Process.reap`.

* 2009-01-27
  ** Added `MLton.Socket.Address.toVector` to get the network-byte-order
  representation of an IP address.

* 2008-11-10
  ** Fixed bug in `MLton.size` and `MLton.share` when tracing the current stack.

* 2008-10-27
  ** Fixed phantom typing of sockets by hiding the representation of socket
  types.  Previously the representation of sockets was revealed rendering the
  phantom types useless.

* 2008-10-10
  ** Fixed bug in nested `_export`/`_import` functions.

* 2008-09-12
  ** Improved constant folding of floating point operations.

* 2008-08-20
```

```
  ** Store the card/cross map at the end of the allocated ML heap; avoids
  possible out of memory errors when resizing the ML heap cannot be followed by
  a card/cross map allocation.

* 2008-07-24
  ** Added support for compiling to a C library. The relevant new compiler
  options are `-ar` and `-format`. Libraries are named based on the name of the
  `-export-header` file. Libraries have two extra methods:
    *** `NAME_open(argc, argv)` initializes the library and runs the SML code
    until it reaches the end of the program. If the SML code exits or raises an
    uncaught exception, the entire program will terminate.
    *** `NAME_close()` will execute any registered atExit functions, any
    outstanding finalizers, and frees the ML heap.

* 2008-07-16
  ** Fixed bug in the name mangling of `_import`-ed functions with the `stdcall`
  convention.

* 2008-06-12
  ** Added `MLton.Pointer.sizeofPointer`.

* 2008-06-06
  ** Added expert command line switch `-emit-main {true|false}`.

* 2008-05-17
  ** Fixed bug in Windows code to page the heap to disk when unable to grow the
  heap to a desired size. Thanks to Sami Evangelista for the bug report.

* 2008-05-10
  ** Implemented `MLton.Cont.isolate`.

* 2008-04-20
  ** Fixed bug in *NIX code to page the heap to disk when unable to grow the
  heap to a desired size. Thanks to Nicolas Bertolotti for the bug report and
  patch.

* 2008-04-07
  ** More flexible active/paused stack resizing policy. +
  Removed `thread-shrink-ratio` runtime option. + Added
  `stack-current-grow-ratio`, `stack-current-max-reserved-ratio`,
  `stack-current-permit-ratio`, `stack-current-shrink-ratio`,
  `stack-max-reserved-ratio`, and `stack-shrink-ratio` runtime options.

* 2008-04-07
  ** Fixed bugs in Basis Library where the representations of `OS.IO.iodesc`,
  `Posix.IO.file_desc`, `Posix.Signal.signal`, `Socket.sock`,
  `Socket.SOGK.sock_type` as integers were exposed.

* 2008-03-14
  ** Added unsafe versions of all of the monomorphic array and vector
  structures.

* 2008-03-02
  ** Fixed bug in Basis Library where the representation of `OS.Process.status`
  as an integer was exposed.

* 2008-02-13
  ** Fixed space-safety bug in RefFlatten optimization (to flatten refs into
  containing data structure). Thanks to Daniel Spoonhower for the bug report and
  initial diagnosis and patch.

* 2008-01-25
```

```
  ** Various updates to GC statistics gathering.  Some basic GC statistics can
  be accessed from SML by `MLton.GC.Statistics.*` functions.

* 2008-01-24
  ** Added primitive (structural) polymorphic hash.

* 2008-01-21
  ** Fixed frontend to accept `op _longvid_` patterns and expressions. Thanks to
     Florian Weimer for the bug report.

* 2008-01-17
  ** Extended `-show-def-use` output to include types of variable definitions.

* 2008-01-09
  ** Extended `MLton_equal` to be a structural equality on all types, including
  `real` and `->` types.

* 2007-12-18
  ** Changed ML-Yacc and ML-Lex to output line directives so that MLton's
  def-use information points to the source files (`.grm` and `.lex`) instead of
  the generated implementations (`.grm.sml` and `.lex.sml`).

* 2007-12-14
  ** Added runtime option `may-page-heap {false|true}`.  By default, MLton will
  not page the heap to disk when unable to grow the heap to a desired size.
  (Previously, this behavior was the default, with no means to disable, with
  security and least-surprise concerns.) Thanks to Wesley Terpstra for the
  patch.
  ** Fixed bug the FFI visible representation of `Int16.int ref` (and references
  of other primitive types smaller than 32-bits) on big-endian platforms. Thanks
  to Dave Herman for the bug report.

* 2007-12-13
  ** Fixed bug in `ImperativeIOExtra.canInput` (`TextIO.canInput`). Thanks to
     Ville Laurikari for the bug report.

* 2007-12-09
  ** Better constant folding of `IntInf` operations.

* 2007-12-07
  ** Fixed bug in algebraic simplification of `RealX` primitives.  `Real.<= (x,
  x)` is `false` when `x` is `NaN`.

* 2007-11-29
  ** Fixed bug in type inference of flexible records.  This would later cause
  the compiler to raise the `TypeError` exception. Thanks to Wesley Terpstra for
  the bug report.

* 2007-11-28
  ** Fixed bug in cross-compilation of `gdtoa` library. Thanks to Wesley
  Terpstra for the bug report and patch.

* 2007-11-20
  ** Fixed bug in RefFlatten optimization (pass to flatten refs into containing
  data structure). Thanks to Ruy LeyWild for the bug report.

* 2007-11-19
  ** Fixed bug in the handling of weak pointers by the mark-compact garbage
  collector. Thanks to Sean McLaughlin for the bug report and Florian Weimer for
  the initial diagnosis.

* 2007-11-07
```

```
  ** Added `%posint` command to `ml-lex`, to set the `yypos` type and allow the
  lexing of multi-gigabyte input files. Thanks to Florian Weimer for the feature
  concept and original patch.

* 2007-11-07
  ** Added command-line switch `-mlb-path-var '<name> <value>'` for specifying
  MLB path variables.

* 2007-11-06
  ** Allow numeric characters in MLB path variables.

* 2007-09-20
  ** Fixed bug in elaboration of structures with signature constraints.  This
  would later cause the compiler to raise the `TypeError` exception. Thanks to
  Vesa Karvonen for the bug report.

* 2007-09-11
  ** Fixed bug in interaction of `_export`-ed functions and signal
  handlers. Thanks to Sean McLaughlin for the bug report.

* 2007-09-03
  ** Fixed bug in implementation of `_export`-ed functions using `char`
  type. Thanks to Katsuhiro Ueno for the bug report.


== Version 20070826

Here are the changes from version 20051202 to version 20070826.

=== Summary

* New platforms:
  ** amd64-linux, amd64-freebsd
  ** hppa-hpux
  ** powerpc-aix
  ** x86-darwin (Mac OS X)
* Compiler.
  ** Support for 64-bit platforms.
    *** Native amd64 codegen.
  ** Command-line switches.
    *** Added: `-codegen amd64`, `-codegen x86`, `-default-type <type>`,
    `-profile-val {false|true}`.
    *** Changed: `-stop f` (file listing now includes `.mlb` files)
  ** Bytecode codegen.
    *** Support for profiling.
    *** Support for exception history.
* Language.
  ** ML Basis annotations.
    *** Removed: `allowExport`, `allowImport`, `sequenceUnit`, `warnMatch`.
* Libraries.
  ** Basis Library.
    *** Added: `PackWord16Big, `PackWord16Little`, `PackWord64Big`,
    `PackWord64Little`.
    *** Bug Fixes: see changelog.
  ** `MLton` structure.
    *** Added: `MLTON_MONO_ARRAY`, `MLTON_MONO_VECTOR`, `MLTON_REAL`,
    `MLton.BinIO.tempPrefix`, `MLton.CharArray`, `MLton.CharVector`,
    `MLton.IntInf.BigWord`, `MLton.IntInf.SmallInt`,
    `MLton.Exn.defaultTopLevelHandler`, `MLton.Exn.getTopLevelHandler`,
    `MLton.Exn.setTopLevelHandler`, `MLton.LargeReal`, `MLton.LargeWord`,
    `MLton.Real`, `MLton.Real32`, `MLton.Real64`, `MLton.Rlimit.Rlim`,
    `MLton.TextIO.tempPrefix`, `MLton.Vector.create`, `MLton.Word.bswap`,
```

```
    `MLton.Word8.bswap`, `MLton.Word16`, `MLton.Word32`, `MLton.Word64`,
    `MLton.Word8Array`, `MLton.Word8Vector`.
    *** Changed: `MLton.Array.unfoldi`, `MLton.IntInf.rep`, `MLton.Rlimit`,
    `MLton.Vector.unfoldi`.
    *** Deprecated: `MLton.Socket`
  ** Other libraries.
    *** Added: MLRISC libary.
    *** Updated: ckit library, SML/NJ library.
* Tools.

=== Details

* 2007-08-12
  ** Removed deprecated ML Basis annotations.

* 2007-08-06
  ** Fixed bug in treatment of `Real<N>.{scan,fromString}` operations.
  `Real<N>.{scan,fromString}` were using `TO_NEAREST` semantics, but should obey
  current rounding mode.  (Only `Real<N>.fromDecimal` is specified to always
  have `TO_NEAREST` semantics.)  Thanks to Sean McLaughlin for the bug report.

* 2007-07-27
  ** Fixed bugs in constant-folding of floating-point operations with C codegen.

* 2007-07-26
  ** Fixed bug in treatment of floating-point operations.  Floating-point
  operations depend on the current rounding mode, but were being treated as
  pure. Thanks to Sean McLaughlin for the bug report.

* 2007-07-13
  ** Added `MLton.Exn.{default,get,set}TopLevelHandler`.

* 2007-07-12
  ** Restored `native` option to `-codegen` flag.

* 2007-07-11
  ** Fixed bug in `Real32.toInt`: conversion of real values close to
  `Int.maxInt` could be incorrect.

* 2007-07-07
  ** Updates to bytecode code generator: support for amd64-* targets, support
  for profiling (including exception history).
  ** Fixed bug in `Socket` module of Basis Library; unmarshalling of socket
  options (for `get*` functions) used `andb` rather than `orb`. Thanks to Anders
  Petersson for the bug report (and patch).

* 2007-07-06
  ** Fixed bug in `Date` module of Basis Library; some functions would
  erroneously raise `Date` when given a year <= 1900. Thanks to Joe Hurd for the
  bug report.
  ** Fixed a long-standing bug in monomorphisation pass. Thanks to Vesa Karvonen
  for the bug report.

* 2007-05-18
  ** Native amd64 code generator for amd64-* targets.
  ** Eliminate `native` option from `-codegen` flag.
  ** Add `x86` and `amd64` options to `-codegen` flag.

* 2007-04-29
  ** Improved type checking of RSSA and Machine ILs.

* 2007-04-14
```

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  ** Fixed aliasing issues with `basis/Real/*.c` files.
  ** Added real/word casts in `MLton` structure.

* 2007-04-12
  ** Added primitives for bit cast of word to/from real.
  ** Implement `PackReal<N>{Big,Little}` using `PackWord<N>{Big,Little}` and bit
  casts.

* 2007-04-11
  ** Move all system header `#include`-s to `platform/` os headers.
  ** Use C99 `<assert.h>`, rather than custom `"assert.{h,c}"`.

* 2007-03-13
  ** Implement `PackWord<N>{Big,Little}` entirely in ML, using an ML byte swap
  function.

* 2007-02-25
  ** Change amd64-* target platforms from 32-bit compatibility mode (i.e.,
  `-m32`) to 64-bit mode (i.e., `-m64`).  Currently, only the C codegen is able
  to generate 64-bit executables.

* 2007-02-23
  ** Removed expert command line switch `-coalesce <n>`.
  ** Added expert command line switch `-chunkify {coalesce<n>|func|one}`.

* 2007-02-20
  ** Fixed bug in `PackReal<N>.toBytes`. Thanks to Eric McCorkle for the bug
  report (and patch).

* 2007-02-18
  ** Added command line switch `-profile-val`, to profile the evaluation of
  `val` bindings; this is particularly useful with exception history for
  debugging uncaught exceptions at the top-level.

* 2006-12-29
  ** Added command line switch `-show {anns|path-map}` and deprecated command
  line switch `-show-anns {false|true}`.  Use `-show path-map` to see the
  complete MLB path map as seen by the compiler.

* 2006-12-20
  ** Changed the output of command line switch `-stop f` to include `.mlb`
  files.  This is useful for generating Makefile dependencies.  The old output
  is easy to recover if necessary (e.g. `grep -v '\.mlb$'`).

* 2006-12-08
  ** Added command line switches `-{,target}-{as,cc,link}-opt-quote`, which pass
  their argument as a single argument to `gcc` (i.e., without tokenization at
  spaces).  These options support using headers and libraries (including the
  MLton runtime headers and libraries) from a path with spaces.

* 2006-12-02
  ** Extensive reorganization of garbage collector, runtime system, and Basis
  Library implementation. (This is in preparation for future 64bit support.)
  They should be more C standards compliant and easier to port to new systems.
  ** FFI revisions
    *** Disallow nested indirect types (e.g., `int array array`).

* 2006-11-30
  ** Fixed a bug in elaboration of FFI forms; unary FFI types (e.g., `array`,
  `ref`, `vector`) could be used in places where `MLton.Pointer.t` was required.
  This would later cause the compiler to raise the `TypeError` exception, along
  with a lot of XML IL.
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* 2006-11-19
  ** On *-darwin, work with GnuMP installed via Fink or MacPorts.

* 2006-10-30
  ** Ported to x86-darwin.

* 2006-09-23
  ** Added missing specification of `find` to the `MONO_VECTOR` signature.

* 2006-08-03
  ** Fixed a bug in Useless SSA optimization, caused by calling an imported C
  function and then ignoring the result.

* 2006-06-24
  ** Fixed a bug in pass to flatten data structures. Thanks to Joe Hurd for the
  bug report.

* 2006-06-08
  ** Fixed a bug in the native codegen's implementation of the C-calling
  convention.

* 2006-05-11
  ** Ported to PowerPC-AIX.
  ** Fixed a bug in the runtime for the cases where nonblocking IO with sockets
  was implemented using `MSG_DONTWAIT`.  This flag does not exist on AIX,
  Cygwin, HPUX, and MinGW and was previously just ignored.  Now the runtime
  simulates the flag for these platforms (except MinGW, yet, where it's still
  ignored).

* 2006-05-06
  ** Added `-default-type '<ty><N>'` for specifying the binding of default types
  in the Basis Library (e.g., `Int.int`).

* 2006-04-25
  ** Ported to HPPA-HPUX.
  ** Fixed `PackReal{,32,64}{Big,Little}` to follow the Basis Library
  specification.

* 2006-04-19
  ** Fixed a bug in `MLton.share` that could cause a segfault.

* 2006-03-30
  ** Changed `MLton.Vector.unfoldi` to return the state in addition to the
  result vector.

* 2006-03-30
  ** Added `MLton.Vector.create`, a more powerful vector-creation function than
  is available in the basis library.

* 2006-03-04
  ** Added MLRISC from SML/NJ 110.57 to standard distribution.

* 2006-03-03
  ** Fixed bug in SSA simplifier that could eliminate an irredundant test.

* 2006-03-02
  ** Ported a bugfix from SML/NJ for a bug with the combination of `withNack`
  and `never` in CML.

* 2006-02-09
  ** Support compiler specific annotations in ML Basis files.  If an annotation
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  contains `:`, then the text preceding the `:` is meant to denote a compiler.
  For MLton, if the text preceding the `:` is equal to `mlton`, then the
  remaining annotation is scanned as a normal annotation.  If the text preceding
  the `:` is not-equal to `mlton`, then the annotation is ignored, and no
  warning is issued.

* 2006-02-04
  ** Fixed bug in elaboration of functors; a program with a very large number of
  functors could exhibit the error `ElaborateEnv.functorClosure: firstTycons`.


== Version 20051202

Here are the changes from version 20041109 to version 20051202.

=== Summary

* New license: BSD-style instead of GPL.
* New platforms:
  ** hppa: Debian Linux.
  ** x86: MinGW.
* Compiler.
  ** improved exception history.
  ** Command-line switches.
    *** Added: `-as-opt`, `-mlb-path-map`, `-target-as-opt`, `-target-cc-opt`.
    *** Deprecated: none.
    *** Removed: `-native`, `-sequence-unit`, `-warn-match`, `-warn-unused`.
* Language.
  ** FFI syntax changes and extensions.
    *** Added: `_symbol`.
    *** Changed: `_export`, `_import`.
    *** Removed: `_ffi`.
  ** ML Basis annotations.
    *** Added: `allowFFI`, `nonexhaustiveExnMatch`, `nonexhaustiveMatch`,
    `redundantMatch`, `sequenceNonUnit`.
    *** Deprecated: `allowExport`, `allowImport`, `sequenceUnit`, `warnMatch`.
* Libraries.
  ** Basis Library.
    *** Added: `Int1`, `Word1`.
  ** `MLton` structure.
    *** Added: `Process.create`, `ProcEnv.setgroups`, `Rusage.measureGC`,
        `Socket.fdToSock`, `Socket.Ctl.getError`.
    *** Changed: `MLton.Platform.Arch`.
  ** Other libraries.
    *** Added: ckit library, ML-NLFFI library, SML/NJ library.
* Tools.
  ** updates of `mllex` and `mlyacc` from SML/NJ.
  ** added `mlnlffigen`.
  ** profiling supports better inclusion/exclusion of code.

=== Details

* 2005-11-19
  ** Updated SML/NJ Library and CKit Library from SML/NJ 110.57.

* 2005-11-15
  ** Fixed a bug in `MLton.ProcEnv.setgroups`.

* 2005-11-11
  ** Fixed a bug in the interleaving of lexing/parsing and elaborating of ML
  Basis files, which would raise an unhandled `Force` exception on cyclic basis
  references. Thanks to John Dias for the bug report.
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* 2005-11-10
  ** Fixed two bugs in `Time.scan`.  One would raise `Time` on a string with a
  large fractional component.  Thanks to Carsten Varming for the bug report.
  The other failed to scan strings with an explicit sign followed by a decimal
  point.

* 2005-11-03
  ** Removed `MLton.GC.setRusage`.
  ** Added `MLton.Rusage.measureGC`.

* 2005-09-11
  ** Fixed bug in display of types with large numbers of type variables, which
  could cause unhandled exception `Chr`.

* 2005-09-08
  ** Fixed bug in type inference of flexible records that would show up as
  `"Type error: variable applied to wrong number of type args"`.

* 2005-09-06
  ** Fixed bug in `Real.signBit`, which had assumed that the underlying C
  signbit returned 0 or 1, when in fact any nonzero value is allowed to indicate
  the signbit is set.

* 2005-09-05
  ** Added `-mlb-path-map` switch.

* 2005-08-25
  ** Fixed bug in `MLton.Finalizable.touch`, which was not keeping alive
  finalizable values in all cases.

* 2005-08-18
  ** Added SML/NJ Library and CKit Library from SML/NJ 110.55 to standard
  distribution.
  ** Fixed bug in `Socket.Ctl.*`, which got the endianness wrong on big-endian
  machines. Thanks to Wesley Terpstra for the bug report and fix.
  ** Added `MLton.GC.setRusage`.
  ** Fixed bug in `mllex`, which had file positions starting at 2.  They now
  start at zero.

* 2005-08-15
  ** Fixed bug in `LargeInt.scan`, which should skip leading `"0x"` and `"0X"`.
  Thanks to Wesley Terpstra for the bug report and fix.

* 2005-08-06
  ** Additional revisions of FFI:
    *** Deprecated `_export` with incomplete annotation.
    *** Added `_address` for address of C objects.
    *** Eliminated address component of `_symbol`.
    *** Changed the type of the `_symbol*` expression.
    *** See documentation for more detail.

* 2005-08-06
  ** Annotation changes:
    *** Deprecated: `sequenceUnit`
    *** Added: `sequenceNonUnit`

* 2005-08-03
  ** Annotation changes:
    *** Deprecated: `allowExport`, `allowImport`, `warnMatch`
    *** Added: `allowFFI`, `nonexhaustiveExnMatch`, `nonexhaustiveMatch`,
    `redundantMatch`
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* 2005-08-01
  ** Update `mllex` and `mlyacc` with SML/NJ 110.55+ versions.  This
  incorporates a small number of minor bug fixes.

* 2005-07-23
  ** Fixed bug in pass to flatten refs into containing data structure.

* 2005-07-23
  ** Overhaul of FFI:
    *** Deprecated `_import` of C base types.
    *** Added `_symbol` for address, getter, and setter of C base types.
    *** See documentation for more detail.

* 2005-07-21
  ** Update `mllex` and `mlyacc` with SML/NJ 110.55 versions.  This incorporates
  a small number of minor bug fixes.

* 2005-07-20
  ** Fixed bug in front end that allowed unary constructors to be used without
  an argument in patterns.

* 2005-07-19
  ** Eliminated `_ffi`, which has been deprecated for some time.

* 2005-07-14
  ** Fixed bug in runtime that caused getrusage to be called on every GC, even
  if timing info isn't needed.

* 2005-07-13
  ** Fixed bug in closure conversion tickled by making a weak pointer to a
  closure.

* 2005-07-12
  ** Changed `{OS,Posix}.Process.sleep` to call `nanosleep()` instead of
  `sleep()`.
  ** Added `MLton.ProcEnv.setgroups`.

* 2005-07-11
  ** `InetSock.{any,toAddr}` raise `SysErr` if port is not in [0, 2^16^).

* 2005-07-02
  ** Fixed bug in `Socket.recvVecFrom{,',NB,NB'}`.  The type was too polymorphic
  and allowed the creation of a bogus `sock_addr`.

* 2005-06-28
  ** The front end now reports errors on encountering undefined or cyclicly
  defined MLB path variables.

* 2005-05-22
  ** Fixed bug in `Posix.IO.{getlk,setlk,setlkw}` that caused a link-time error:
  undefined reference to `Posix_IO_FLock_typ`.
  ** Improved exception history so that the first entry in the history is the
  source position of the raise, and the rest is the call stack.

* 2005-05-19
  ** Improved exception history for `Overflow` exceptions.

* 2005-04-20
  ** Fixed a bug in pass to flatten refs into containing data structure.

* 2005-04-14
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  ** Fixed a front-end bug that could cause an internal bug message of the form
  `"missing flexInst"`.

* 2005-04-13
  ** Fixed a bug in the representation of flat arrays/vectors that caused
  incorrect behavior when the element size was 2 or 4 bytes and there were
  multiple components to the element (e.g. `(char * char) vector`).

* 2005-04-01
  ** Fixed a bug in `GC_arrayAllocate` that could cause a segfault.

* 2005-03-22
  ** Added structures `Int1`, `Word1`.

* 2005-03-19
  ** Fixed a bug that caused `Socket.Ctl.{get,set}LINGER` to raise `Subscript`.
  The problem was in the use of `PackWord32Little.update`, which scales the
  supplied index by `bytesPerElem`.

* 2005-03-13
  ** Fixed a bug in CML mailboxes.

* 2005-02-26
  ** Fixed an off-by-one error in `mkstemp` defined in `mingw.c`.

* 2005-02-13
  ** Added `mlnlffigen` tool (heavily adapted from SML/NJ).

* 2005-02-12
  ** Added MLNLFFI Library (heavily adapted from SML/NJ) to standard
  distribution.

* 2005-02-04
  ** Fixed a bug in `OS.path.toString`, which did not raise `InvalidArc` when
  needed.

* 2005-02-03
  ** Fixed a bug in `OS.Path.joinDirFile`, which did not raise `InvalidArc` when
  passed a file that was not an arc.

* 2005-01-26
  ** Fixed a front end bug that incorrectly rejected expansive __valbind__s with
  useless bound type variables.

* 2005-01-22
  ** Fixed x86 codegen bug which failed to account for the possibility that a
  64-bit move could interfere with itself (as simulated by 32-bit moves).

* 2004-12-22
  ** Fixed `Real32.fmt StringCvt.EXACT`, which had been producing too many
  digits of precision because it was converting to a `Real64.real`.

* 2004-12-15
  ** Replaced MLB path variable `MLTON_ROOT` with `SML_LIB`, to use a more
  compiler-independent name.  We will keep `MLTON_ROOT` aliased to `SML_LIB`
  until after the next release.

* 2004-12-02
  ** `Unix.create` now works on all platforms (including Cygwin and MinGW).

* 2004-11-24
  ** Added support for `MLton.Process.create`, which works on all platforms
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  (including Windows-based ones like Cygwin and MinGW) and allows better control
  over `std{in,out,err}` for child process.


== Version 20041109

Here are the changes from version 20040227 to 20041109.

=== Summary

* New platforms:
  ** x86: FreeBSD 5.x, OpenBSD
  ** PowerPC: Darwin (MacOSX)
* Support for MLBasis files.
* Support for dynamic libraries.
* Support for Concurrent ML (CML).
* New structures: `Int2`, `Int3`, ..., `Int31` and `Word2`, `Word3`, ..., `Word31`.
* A new form of profiling: `-profile count`.
* A bytecode generator.
* Data representation improvements.
* `MLton` structure changes.
   ** Added: `share`, `shareAll`
   ** Changed: `Exn`, `IntInf`, `Signal`, `Thread`.
* Command-line switch changes.
   ** Deprecated:
     *** `-native` (use `-codegen`)
     *** `-sequence-unit` (use `-default-ann`)
     *** `-warn-match` (use `-default-ann`)
     *** `-warn-unused` (use `-default-ann`)
   ** Removed:
     *** `-detect-overflow`
     *** `-exn-history` (use `-const`)
     *** `-safe`
     *** `-show-basis-used`
   ** Added:
     *** `-codegen`
     *** `-const`
     *** `-default-ann`
     *** `-disable-ann`
     *** `-profile-branch`
     *** `-target-link-opt`

=== Details

* 2004-09-22
  ** Extended `_import` to support indirect function calls.

* 2004-09-13
  ** Made `Date.{fromString,scan}` accept a space (treated as zero) in the first
  character of the day of the month.

* 2004-09-12
  ** Fixed bug in `IntInf` that could cause a segfault.
  ** Remove `MLton.IntInf.size`.

* 2004-09-05
  ** Made `-detect-overflow` and `-safe` expert options.

* 2004-08-30
  ** Added `val MLton.share: 'a -> unit`, which maximizes sharing in a heap
  object.
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* 2004-08-27
  ** Fixed bug in `Real.toLargeInt`.  It would incorrectly raise `Option`
  instead of `Overflow` in the case when the real was not an `INF`, but rounding
  produced an `INF`.
  ** Fixed bugs in `Date.{fmt,fromString,scan,toString}`.  They incorrectly
  allowed a space for the first character in the day of the month.

* 2004-08-18
  ** Changed `MLton.{Thread,Signal,World}` to distinguish between implicitly and
  explicitly paused threads.

* 2004-07-28
  ** Added support for programming in the large using the ML Basis system.

* 2004-07-11
  ** Fixed bugs in `ListPair.*Eq` functions, which incorrectly raised the
  `UnequalLengths` exception.

* 2004-07-01
  ** Added `val MLton.Exn.addExnMessager: (exn -> string option) -> unit`.

* 2004-06-23
  ** Runtime system options that take memory sizes now accept a "`g`" suffix
  indicating gigabytes.  They also now take a real instead of an integer,
  e.g. `fixed-heap 0.5g`.  They also now accept uppercase, e.g. `150M`.

* 2004-06-12
  ** Added support for OpenBSD.

* 2004-06-10
  ** Added support for FreeBSD 5.x.

* 2004-05-28
  ** Deprecated the `-native` flag.  Instead, use the new flag `-codegen
  {native|bytecode|C}`.  This is in anticipation of adding a bytecode compiler.

* 2004-05-26
  ** Fixed a front-end bug that could cause cascading error to print a very
  large and unreadable internal bug message of the form `"datatype ... realized
  with scheme Unknown"`.

* 2004-05-17
  ** Automatically restart functions in the Basis Library that correspond
  directly to interruptable system calls.

* 2004-05-13
  ** Added `-profile count`, for dynamic counts of function calls and branches.
  ** Equate the types `Posix.Signal.signal` and `Unix.signal`.

* 2004-05-11
  ** Fixed a bug with `-basis 1997` that would cause type errors due to
  differences between types in the MLton structure and types in the rest of the
  basis library.

* 2004-05-01
  ** Fixed a bug with sharing constraints in signatures that would sometimes
  mistakenly treat two structures as identical when they shouldn't have been.
  This would cause some programs to be mistakenly rejected.

* 2004-04-30
  ** Added `MLton.Signal.{handled,restart}`.
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* 2004-04-23
  ** Added `Timer.checkCPUTimes`, and updated the `Timer` structure to match the
    latest basis spec.  Also fixed `totalCPUTimer` and `totalRealTimer`, which
    were wrong.

* 2004-04-13
  ** Added `MLton.Signal.Mask.{getBlocked,isMember}`.

* 2004-04-12
  ** Fix bug that mistakenly generalized variable types containing unknown types
  when matching against a signature.
  ** Reasonable front-end error message when unification causes recursive
  (circular) type.

* 2004-04-03
  ** Fixed bug in sharing constraints so that `sharing A = B = C` means that all
  pairs `A = B`, `A = C`, `B = C` are shared, not just `A = B` and `B = C`.
  This matters in some situations.

* 2004-03-20
  ** Fixed `Time.now` which was treating microseconds as nanoseconds.

* 2004-03-14
  ** Fixed SSA optimizer bug that could cause the error `"<type> has no
  tyconInfo property"`.

* 2004-03-11
  ** Fixed `Time.fromReal` to raise `Time`, not `Overflow`, on unrepresentable
  times.

* 2004-03-04
  ** Added structures `Word2`, `Word3`, ..., `Word31`.

* 2004-03-03
  ** Added structures `Int2`, `Int3`, ..., `Int31`.
  ** Fixed bug in elaboration of `and` with signatures, structures, and functors
  so that it now evaluates all right-hand sides before binding any left-hand
  sides.


== Version 20040227

Here are the changes from version 20030716 to 20040227.

=== Summary

* The front end now follows the Definition of SML and produces readable error
messages.
* Added support for NetBSD.
* Basis library changes tracking revisions to the specification.
* Added structures: `Int64`, `Real32`, `Word64`.
* File positions use `Int64`.
* Major improvements to `-show-basis`, which now displays the basis in a very
readable way with full type information.
* Command-line switch changes.
   ** Deprecated: `-basis`.
   ** Removed: `-lib-search`, `-link`, `-may-load-world`, `-static`.
   ** Added: `-link-opt`, `-runtime`, `-sequence-unit`, `-show-def-use`,
   `-stop tc`, `-warn-match`, `-warn-unused`.
   ** Changed: `-export-header`, `-show-basis`, `-show-basis-used`.
   ** Renamed: `-host` to `-target`.
* FFI changes.
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  ** Renamed `_ffi` as `_import`.
  ** Added `cdecl` and `stdcall` attributes to `_import` and `_export`
  expressions.
* MLton structure changes.
  ** Added: Pointer.
  ** Removed: Ptrace.
  ** Changed: `Finalizable`, `IntInf`, `Platform`, `Random`, `Signal`, `Word`.

=== Details

* 2004-02-16
  ** Changed `-export-header`, `-show-basis`, `-show-basis-used` to take a file
  name argument, and they no longer force compilation to halt.
  ** Added `-show-def-use` and `-warn-unused`, which deal with def-use
  information.

* 2004-02-13
  ** Added flag `-sequence-unit`, which imposes the constraint that in the
  sequence expression `(e1; e2)`, `e1` must be of type `unit`.

* 2004-02-10
  ** Lots of changes to `MLton.Signal`: name changes, removal of superfluous
  functions, additional functions.

* 2004-02-09
  ** Extended `-show-basis` so that when used with an input program, it shows
  the basis defined by the input program.
  ** Added `stop` runtime argument.
  ** Made `-call-graph {false|true}` an option to `mlprof` that determines
  whether or not a call graph file is written.

* 2004-01-20
  ** Fixed a bug in `IEEEReal.{fromString,scan}`, which would improperly return
  `INF` instead of `ZERO` for things like `"0.0000e123456789012345"`.
  ** Fixed a bug in `Real.{fromDecimal,fromString,scan}`, which didn't return an
  appropriately signed zero for `~0.0`.
  ** Fixed a bug in `Real.{toDecimal,fmt}`, which didn't correctly handle
  `~0.0`.
  ** Report a compile-time error on unrepresentable real constants.

* 2004-01-05
  ** Removed option `-may-load-world`.  You can now use `-runtime no-load-world`
  instead.
  ** Removed option `-static`.  You can now use `-link-opt -static` instead.
  ** Changed `MLton.IntInf.size` to return 0 instead of 1 on small ints.

* 2003-12-28
  ** Fixed horrible bug in `MLton.Random.alphaNumString` that caused it to
  return 0 for all characters beyond position 11.

* 2003-12-17
  ** Removed `-basis` as a normal flag.  It is still available as an expert
  flag, but its use is deprecated.  It will almost certainly disappear after the
  next release.

* 2003-12-10
  ** Allow multiple `@MLton --` runtime args in sequnce.  This makes it easier
  for scripts to prefix `@MLton` args without having to splice them with other
  ones.

* 2003-12-04
  ** Added support for files larger than 2G.  This included changing
```

```
  `Position` from `Int32` to `Int64`.

* 2003-12-01
  ** Added `structure MLton.Pointer`, which includes a `type t` for pointers
  (memory addresses, not SML heap pointers) and operations for loading from and
  storing to memory.

* 2003-11-03
  ** Fixed `Timer.checkGCTime` so that only the GC user time is included, not GC
  system time.

* 2003-10-13
  ** Added `-warn-match` to control display nonexhaustive and redundant
  match warnings.
  ** Fixed space leak in `StreamIO` causing the entire stream to be retained.
  Thanks to Jared Showalter for the bug report and fix.

* 2003-10-10
  ** Added `-stop tc` switch to stop after type checking.

* 2003-09-25
  ** Fixed `Posix.IO.getfl`, which had mistakenly called `fcntl` with `F_GETFD`
  instead of `F_GETFL`.
  ** Tracking basis library changes:
    *** `Socket` module datagram functions no longer return amount written,
    since they always write the entire amount or fail.  So,
    `send{Arr,Vec}To{,'}` now return `unit` instead of `int`.
    *** Added nonblocking versions of all the send and recv functions, as well
    as accept and connect.  So, we now have: `acceptNB`, `connectNB`,
    `recv{Arr,Vec}{,From}NB{,'}`, `send{Arr,Vec}{,To}NB{,'}`.

* 2003-09-24
  ** Tracking basis library changes:
    *** `TextIO.inputLine` now returns a `string option`.
    *** Slices used in `Byte`, `PRIM_IO`, `PrimIO`, `Posix.IO`, `StreamIO`.
    *** `Posix.IO.readVec` raises `Size`, not `Subscript`, with negative
    argument.

* 2003-09-22
  ** Fixed `Real.toManExp` so that the mantissa is in [0.5, 1), not [1, 2).  The
  spec says that 1.0 <= man * radix < radix, which since radix is 2, implies
  that the mantissa is in [0.5, 1).
  ** Added `Time.{from,to}Nanoseconds`.

* 2003-09-11
  ** Added `Real.realRound`.
  ** Added `Char{Array,Vector}Slice` to `Text`.

* 2003-09-11
  ** `OS.IO.poll` and `Socket.select` now raise errors on negative timeouts.
  ** `Time.time` is now implemented using `IntInf` instead of `Int`, which means
  that a much larger range of time values is representable.

* 2003-09-10
  ** `Word64` is now there.

* 2003-09-09
  ** Replaced `Pack32{Big,Little}` with `PackWord32{Big,Little}`.
  ** Fixed bug in `OS.FileSys.fullPath`, which mistakenly stopped as soon as it
  hit a symbolic link.

* 2003-09-08
```

```
  ** Fixed `@MLton max-heap`, which was mistakenly ignored.  Cleaned up `@MLton
  fixed-heap`.  Both `fixed-heap` and `max-heap` can use copying or mark-compact
  collection.

* 2003-09-06
  ** `Int64` is completely there.
  ** Fixed `OS.FileSys.tmpName` so that it creates the file, and doesn't use
  `tmpnam`.  This eliminates an annoying linker warning message.

* 2003-09-05
  ** Added structures `{LargeInt,LargeReal,LargeWord,Word}{Array,Array2,ArraySlice,Vector, ↩
     VectorSlice}`
  ** Fixed bug in `Real.toDecimal`, which return class `NORMAL` for subnormals.
  ** Fixed bug in `Real.toLargeInt`, which didn't return as precise an integer
  as possible.

* 2003-09-03
  ** Lots of fixes to `REAL` functions.
    *** `Real32` is now completely in place, except for `Real32.nextAfter` on
    SunOS.
    *** Fixed `Real.Math.exp` on x86 to return the right value when applied to
    `posInf` and `negInf`.
    *** Changed `Real.Math.{cos,sin,tan}` on x86 to always use a call to the C
    math library instead of using the x86 instruction.  This eliminates some
    anomalies between compiling `-native false` and `-native true`.
    *** Change `Real.Math.pow` to handle exceptional cases in the SML code.
    *** Fixed `Real.signBit` on Sparcs.

* 2003-08-28
  ** Fixed `PackReal{,64}Little` to work correctly on Sparc.
  ** Added `PackReal{,64}Big`, `PackReal32{Big,Little}`.
  ** Added `-runtime` switch, which passes arguments to the runtime via
  `@MLton`.  These arguments are processed before command line switches.
  ** Eliminated MLton switch `-may-load-world`.  Can use `-runtime` combined
  with new runtime switch `-no-load-world` to disable load world in an
  executable.

* 2003-08-26
  ** Changed `-host` to `-target`.
  ** Split `MLton.Platform.{arch,os}` into `MLton.Platform.{Arch,OS}.t`.

* 2003-08-21
  ** Fixed bug in C codegen that would cause undefined references to
  `Real_{fetch,move,store}` when compiling on Sparcs with `-align 4`.

* 2003-08-17
  ** Eliminated `-link` and `-lib-search`, which are no longer needed.
  Eliminated support for passing `-l*`, `-L*`, and `*.a` on the command line.
  Use `-link-opt` instead.

* 2003-08-16
  ** Added `-link-opt`, for passing options to `gcc` when linking.

* 2003-07-19
  ** Renamed `_ffi` as `_import`.  The old `_ffi` will remain for a while, but
  is deprecated and should be replaced with `_import`.
  ** Added attributes to `_export` and `_import`.  For now, the only attributes
  are `cdecl` and `stdcall`.


== Version 20030716
```

```
Here are the changes from version 20030711 to 20030716.

== Summary

* Fixed several serious bugs with the 20030711 release.

== Details

* 2003-07-15
  ** Fixed bug that caused a segfault when attempting to create an
  array that was too large, e.g

      1 + Array.sub (Array.tabulate (valOf Int.maxInt, fn i => i), 0)

  ** mlton now checks the command line arguments following the file to compile
  that are passed to the linker to make sure they are reasonable.

* 2003-07-14
  ** Fixed packaging for Cygwin and Sparc to include `libgmp.a`.
  ** Eliminated bootstrap target.  The `Makefile` automatically determines
  whether to bootstrap or not.
  ** Fixed XML type checker bug that could cause error: `"empty tyvars in
  PolyVal dec"`.

* 2003-07-12
  ** Turned off `FORCE_GENERATIONAL` in gc.  It had been set, which caused the
  gc to always use generational collection.  This could seriously slow apps down
  that don't need it.


== Version 20030711

Here are the changes from version 20030312 to 20030711.

=== Summary

* Added support for Sparc/SunOS using the C code generator.
* Completed the basis library implementation.  At this point, the only missing
basis library function is `use`.
* Added `_export`, which allows one to call SML functions from C.
* Added weak pointers (via `MLton.Weak`) and finalization (via
`MLton.Finalizable`).
* Added new integer modules: `Int8`, `Int16`.
* Better profiling call graphs
* Fixed conversions between reals and their decimal representations to be
correct using the gdtoa library.

=== Details

* 2003-07-07
  ** Profiling improvements:
    *** Eliminated `mlton -profile-split`.  Added `mlprof -split`.  Now the
    profiling infrastructure keeps track of the splits and allows one to decide
    which splits to make (if any) when `mlprof` is run, which is much better
    than having to decide at compile time.
    *** Changed `mlprof -graph` to `mlprof -keep`, and changed the behavior so
    that `-keep` also controls which functions are displayed in the table.
    *** Eliminated `mlprof -ignore`: it's behavior is now subsumed by `-keep`,
    whose meaning has changed to be more like -ignore on nodes that are not
    kept.
  ** When calling `gcc` for linking, put `-link` args in same order as they
  appeared on the MLton command line (they used to be reversed).
```

```
* 2003-07-03
  ** Making `OS.Process.{atExit,exit}` conform to the basis library spec in that
  exceptions raised during cleaners are caught and ignored.  Also, calls to
  `exit` from cleaners cause the rest of cleaners to run.

* 2003-07-02
  ** Fixed bug with negative `IntInf` constants that could cause compile time
  error message: `"x86Translate.translateChunk ... strange Offset: base: ..."`
  ** Changed argument type of `MLton.IntInf.Small` from `word` to `int`.
  ** Added fix to profiling so that the `mlmon.out` file is written even when
  the program terminates due to running out of memory.

* 2003-06-25
  ** Added `{Int{8,16},Word8}{,Array,ArraySlice,Vector,VectorSlice,Array2}`
  structures.

* 2003-06-25
  ** Fixed bug in `IntInf.sign`, which returned the wrong value for zero.

* 2003-06-24
  ** Added `_export`, for calling from C to SML.

* 2003-06-18
  ** Regularization of options:
    *** `-diag` --> `-diag-pass`
    *** `-drop-pass` takes a regexp

* 2003-06-06
  ** Fixed bug in `OS.IO.poll` that caused it to return the input event types
  polled for instead of what was actually available.

* 2003-06-04
  ** Fixed bug in KnownCase SSA optimization that could case incorrect results
  in compiled programs.

* 2003-06-03
  ** Fixed bug in SSA optimizer that could cause the error message:

      Type error: Type.equals
      {from = char vector, to = unit vector}
      Type error: analyze raised exception loopStatement: ...
      unhandled exception: TypeError

* 2003-06-02
  ** Fixed `Real.rem` to work correctly on `inf`-s and `nan`-s.
  ** Fixed bug in profiling that caused the function name to be omitted on
  functions defined by `val rec`.

* 2003-05-31
  ** `Fixed Real.{fmt,fromString,scan,toString}` to match the basis library
  spec.
  ** Added `IEEEReal.{fromString,scan}`.
  ** Added `Real.{from,to}Decimal`.

* 2003-05-25
  ** Added `Real.nextAfter`.
  ** Added `OS.Path.{from,to}UnixPath`, which are the identity function on Unix.

* 2003-05-20
  ** Added type `MLton.pointer`, the type of C pointers, for use with the FFI.
```

```
* 2003-05-18
  ** Fixed two bugs in type inference that could cause the compiler to raise the
  `TypeError` exception, along with a lot of XML IL.  The `type-check.sml`
  regression contains simple examples of what failed.
  ** Fixed a bug in the simplifier that could cause the message: `"shrinker
  raised Prim.apply raised assertion failure: SmallIntInf.fromWord"`.

* 2003-05-15
  ** Fixed bug in `Real.class` introduced on 04-28 that cause many regression
  failures with reals when using newer `gcc`-s.
  ** Replaced `MLton.Finalize` with `MLton.Finalizable`, which has a more robust
  approach to finalization.

* 2003-05-13
  ** Fixed bug in `MLton.FFI` on Cygwin that caused `Thread_returnToC` to be
  undefined.

* 2003-05-12
  ** Added support for finalization with `MLton.Finalize`.

* 2003-05-09
  ** Fixed a runtime system bug that could cause a segfault.  This bug would
  happen after a GC during heap resizing when copying a heap, if the heap was
  allocated at a very low (<10M) address.  The bug actually showed up on a
  Cygwin system.

* 2003-05-08
  ** Fixed bug in `HashType` that raised `"Vector.forall2"` when the arity of a
  type constructor is changed by `SimplifyTypes`, but a newly constructed type
  has the same hash value.

* 2003-05-02
  ** Switched over to new layered IO implementation, which completes the
  implementation of the `BinIO` and `TextIO` modules.

* 2003-04-28
  ** Fixed bug that caused an assertion failure when generating a jump table for
  a case dispatch on a non-word sized index with non-zero lower bound on the
  range.

* 2003-04-24
  ** Added `-align {4|8}`, which controls alignment of objects.  With `-align
  8`, memory accesses to doubles are guaranteed to be aligned mod 8, and so
  don't need special routines to load or store.

* 2003-04-22
  ** Fixed bug that caused a total failure of time profiling with `-native
  false`.  The bug was introduced with the C codegen improvements that split the
  C into multiple files.  Now, the C codegen declares all profile labels used in
  each file so that they are global symbols.

* 2003-04-18
  ** Added `MLton.Weak`, which supports weak pointers.

* 2003-04-10
  ** Replaced the basis library's `MLton.hostType` with `MLton.Platform.arch`
  and `MLton.Platform.os`.

* 2003-04
  ** Added support for SPARC/SunOS using the C codegen.

* 2003-03-25
```

```
  ** Added `MLton.FFI`, which allows callbacks to SML from C.

* 2003-03-21
  ** Fixed `mlprof` so that the default `-graph arg` for data from
  `-profile-stack true` is `(thresh-stack x)`, not `(thresh x)`.


== Version 20030312

Here are the changes from version 20020923 to 20030312.

=== Summary

* Added source-level profiling of both time and allocation.
* Updated basis library to 2002 specification.  To obtain the old
library, compile with `-basis 1997`.
* Added many modules to basis library:
 ** `BinPrimIO`, `GenericSock`, `ImperativeIO`, `INetSock`, `NetHostDB`,
 `NetProtDB`, `NetServDB`, `Socket`, `StreamIO`, `TextPrimIO`, `UnixSock`.
* Completed implementation of `IntInf` and `OS.IO`.

=== Details

* 2003-02-23
  ** Replaced `-profile-combine` wih `-profile-split`.

* 2003-02-11
  ** Regularization of options:
    *** `-l` --> `-link`
    *** `-L` --> `-lib-search`
    *** `-o` --> `-output`
    *** `-v` --> `-verbose`

* 2003-02-10
  ** Added option to `mlton`: `-profile-combine {false|true}`

* 2003-02-09
  ** Added options to `mlprof`: `-graph-title`, `-gray`, `-ignore`, `-mlmon`,
  `-tolerant`.

* 2002-11 - 2003-01
  ** Added source-level allocation and time profiling.  This includes the new
  options to mlton: `-profile` and `-profile-stack`.

* 2002-12-28
  ** Added `NetHostDB`, `NetProtDB`, `NetServDB` structures.
  ** Added `Socket`, `GenericSock`, `INetSock`, `UnixSock` structures.

* 2002-12-19
  ** Fixed bug in signal check insertion that could cause some signals to be
  missed.  The fix was to add a signal check on entry to each function in
  addition to at each loop header.

* 2002-12-10
  ** Fixed bug in runtime that might cause the message `"Unable to set
  cardMapForMutator"`.

* 2002-11-23
  ** Added support for the latest Basis Library specification.
  ** Added option `-basis` to choose Basis Library version.  Currently available
    basis libraries are `2002`, `2002-strict`, `1997`, and `none`.
  ** Added `IntInf.{orb,xorb,andb,notb,<<,~>>}` values.
```

```
  ** Added `OS.IO.{poll_desc,poll_info}` types.
  ** Added `OS.IO.{pollDesc,pollToIODesc,infoToPollDesc,Poll}` values.
  ** Added `OS.IO.{pollIn,pollOut,pollPri,poll,isIn,isOut,isPri}` values.
  ** Added `BinPrimIO`, `TextPrimIO` structures.
  ** Added `StreamIO`, `ImperativeIO` functors.

* 2002-11-22
  ** Fixed bug that caused time profiling to fail (with a segfault) when
  resuming a saved world.

* 2002-11-07
  ** Fixed bug in `MLton.eq` that could arise when using `eq` on functions.

* 2002-11-05
  ** Improvements to polymorphic equality.  Equality on IntInfs, vectors, and
  dataypes all do an `eq` test first before a more expensive comparison.

* 2002-11-01
  ** Added allocation profiling.  Now, can compile with either `-profile alloc`
  or `-profile time`.  Renamed `MLton.Profile` as `MLton.ProfileTime`.  Added
  `MLton.ProfileAlloc`.  Cleaned up and changed most `mlprof` option names.

* 2002-10-31
  ** Eliminated `MLton.debug`.
  ** Fixed bug in the optimizer that affected `IntInf.fmt`.  The optimizer had
  been always using base 10, instead of the passed in radix.

* 2002-10-22
  ** Fixed `Real.toManExp` so that the mantissa is in [1, 2), not [0.5, 1).
  ** Added `Real.fromLargeInt`, `Real.toLargeInt`.
  ** Fixed `Real.split`, which would return an incorrect whole part due to the
  underlying primitive, `Real_modf`, being treated as functional instead of
  side-effecting.

* 2002-09-30
  ** Fixed `rpath` problem with packaging.  All executables in packages
  previously made had included a setting for `RPATH`.


== Version 20020923

Here are the changes from version 20020410 to 20020923.

=== Summary

* MLton now runs on FreeBSD.
* Major runtime system improvements.  The runtime now implements mark-compact
and generational collection, in addition to the copying collection that was
there before.  It automatically switches between the the collection strategies
to improve performance and to try to avoid paging.
* Performance when compiling `-exn-history true` has been improved.
* Added `IntInf.log2`, `MLton.GC.pack`, `MLton.GC.unpack`.
* Fixed bug in load world that could cause "sread failed" on Cygwin.
* Fixed optimizer bug that could cause `"no analyze var value property"`
message.

=== Details

* 2002-09
  ** Integrated Sam Rushing's changes to port MLton to FreeBSD.

* 2002-08-25
```

```
  ** Changed the implementation of exception history to be completely
  functional.  Now, the extra field in exceptions (when compiling `-exn-history
  true`) is a `string list` instead of a `string list ref`, and `raise` conses a
  new exception with a new element in the list instead of assigning to the list.
  This changes the semantics of exception history (for the better) on some
  programs. See `regression/exnHistory3.sml` for an example.  It also
  significantly improves performance when compiling `-exn-history true`.

* 2002-07 and 2002-08
  ** Added generational GC, and code to the runtime that automatically turns it
  on and off.

* 2002-08-20
  ** Fixed SSA optimizer bug that could cause the following error message: `"x_0
  has no analyze var value property"`

* 2002-07-28
  ** Added `MLton.GC.{pack,unpack}`.  `pack` shrinks the heap so that other
  processes can use the RAM, and its dual, `unpack`, resizes the heap to the
  desired size.

* 2002-06 and 2002-07
  ** Added mark compact GC.
  ** Changed array layout so that arrays have three, not two header words.  The
  new word is a counter word that preceeds the array length and header.
  ** Changed all header words to be indices into an array of object descriptors.

* 2002-06-27
  ** Added patches from Michael Neumann to port runtime to FreeBSD 4.5.

* 2002-06-05
  ** Output file and intermediate file are now saved in the current directory
  instead of in the directory containing the input file.

* 2002-05-31
  ** Fixed bug in overloading of `/` so that the following now type checks:

      fun f (x, y) = x + y / y

* 2002-04-26
  ** Added back `max-heap` runtime option.

* 2002-04-25
  ** Fixed load/save world so that they use binary mode.  This should fix the
  `sread failed` problem that Byron Hale saw on Cygwin that caused `mlton` to
  fail to start.
  ** Added `IntInf.log2`.
  ** Changed call to linker to use `libgmp.a` (if it exists) instead of
  `libgmp.so`.  This is because the linker adds a dependency to a shared library
  even if there are no references to it

* 2002-04-23
  ** Rewrote heap resizing code.  This fixed bug that was triggered with large
  heaps and could cause a spurious out of memory error.
  ** Removed GnuMP from MLton sources (again :-).


== Version 20020410

Here are the changes from version 20011006 to version 20020410.

=== Details
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* 2002-03-28
  ** Added BinIO.

* 2002-03-27
  ** Regularization of options
    *** `-g` --> `-degug {false|true}`
    *** `-h n` --> `-fixed-heap n`
    *** `-p` --> `-profile {false|true}`

* 2002-03-22
  ** Set up the stubs so that MLton can be compiled in the standard basis
  library, with no `MLton` structure.  Thus it is now easy to compile MLton with
  an older (or newer) version of itself that has a different `MLton` structure.

* 2002-03-17
  ** Added `MLton.Process.{spawn,spawne,spawnp}`, which use primitives when
  running on Cygwin and fork/exec when running on Linux.

* 2002-02 - 2002-03
  ** Added the ability to cross-compile to Cygwin/Windows.

* 2002-02-24
  ** Added GnuMP back for use with Cygwin.

* 2002-02-10
  ** Reworked object header words so that `Array.maxLen = valOf Int.maxInt`.
  Also fixed a long-standing minor bug in MLton, where `Array.array
  (Array.maxLen, ...)` would raise `Size` instead of attempting to allocate the
  array.  It was an off-by-one error in the meaning of `Array.maxLen`.

* 2002-02-08
  ** Modifications to runtime to behave better in situations where the amount of
  live data is a signifant fraction of the amount of RAM, based on code from
  PolySpace.  MLton executables by default can now use more than the available
  amount of RAM.  Executables will still respect the `max-heap` runtime arg if
  it is set.

* 2002-02-04
  ** Improvements to runtime so that it fails to get space, it attempts to get
  less space instead of failing.  Based on PolySpace's modifications.
  ** Added `MLton.eq`.

* 2002-02-03
  ** Added `MLton.IntInf.gcd`.
  ** Removed GnuMP from MLton sources.  We now link with `/usr/lib/libgmp.a`.
  ** Added `TextIO.getPosOut`.
  ** Renamed type `MLton.Itimer.which` to `MLton.Itimer.t` and
  `MLton.Itimer.whichSignal` to `MLton.Itimer.signal`.
  ** Added `-coalesce` flag, for use with the C backend.

* 2002-01-26
  ** Added `-show-basis-used`, which prints out the parts of the basis library
  that the input program uses.
  ** Changed several other flags (`-print-at-fun-entry`, `-show-basis`,
  `-static`) to follow the `{false|true}` convention.

* 2002-01-22
  ** Improved `MLton.profile` so that multiple profile arrays can exist
  simultaneously and so that the current one being used can be set from the SML
  side.
```

```
* 2002-01-18
  ** The Machine IL has been replaced with an RSSA (representation explicit SSA)
  IL and an improved Machine IL.

* 2002-01-16
  ** Added KnownCase SSA optimization

* 2002-01-14
  ** Added rudimentary profiling control from with a MLton compile program via
  the `MLton.Profile` structure.

* 2002-01-09
  ** Fixed bug in match compiler that caused case expressions on datatypes with
  redundant cases to be compiled incorrectly.

* 2002-01-08
  ** Added redundant tuple construction elimination to SSA shrinker.
  ** Improved Flatten SSA optimization.

* 2001-12-06
  ** Changed the interface for `MLton.Signal`.  There is no longer a separate
  `Handler` substructure.  This was done so that programs that just use
  `default` and `ignore` signal handlers don't bring in the entire thread
  mechanism.

* 2001-12-05
  ** Added LocalRef elimination SSA optimization.

* 2001-11-19
  ** The CPS IL has been replaced with an SSA (static-single assignment) IL.
  All of the optimizations have been ported from CPS to SSA.

* 2001-10-24
  ** Fixed bug in `Thread_atomicEnd` -- `limit` was mistakenly set to `base`
  instead of to 0.  This caused assertion failures when for executables compiled
  `-g` because `GC_enter` didn't reset `limit`.
  ** Fixed bug in register allocation of byte registers.

* 2001-10-23
  ** Added `-D` option to `cmcat` for preprocessor defines.  Thanks to Anoq for
  sending the code.
  ** Changed limit check insertion so that limit checks are only coalesced
  within a single basic block -- not across blocks.  This slows many benchmarks
  down, but is needed to fix a bug in the way that limit checks were coalesced
  across blocks.  Hopefully we will figure out a better fix soon.

* 2001-10-18
  ** Fixed type inference of flexrecord so that it now follows the Definition.
  Many programs containing flexrecords were incorrectly rejected.  Added many
  new tests to regression/flexrecord.sml.
  ** Changed the behavior of `-keep dot` combined with `-keep pass` for SSA
  passes.  Dot files are now saved for the program before and after, instead of
  just after.

* 2001-10-11
  ** Fixed a bug in the type inference that caused type variables to be
  mistakenly generalized.  The bug was exposed in Norman Ramsey's `sled.sml`.
  Added a test to `regression/flexrecord.sml` to catch the problem.


== Version 20011006
```

```
Here are the changes from version 20010806 to version 20011006.

=== Summary

* Added `MLton.Exn.history`, which is similar to `SMLofNJ.exnHistory`.
* Support for `#line` directives of the form `(*#line line.col "file"*)`.
* Performance improvements in native codegenerator.
* Bug fixes in front-end, optimizer, register allocator,
`Real.{maxFinite,minPos,toManExp}`, and in heap save and restore.

=== Details

* 2001-10-05
  ** Fixed a bug in polymorphic layered patterns, like

      val 'a a as b = []

  These would always fail due to the variable `a` not being handled correctly.
  ** Fixed the syntax of `val rec` so that a pattern is allowed on the left-hand
  side of the `=`.  Thus, we used to reject, but now accept, the following.

      val rec a as b as c = fn _ => ()
      val rec a : unit -> unit : unit -> unit = fn () => ()

  Thanks again to Andreas Rossberg's test files.  This is now tested for in
  `valrec.sml`.
  ** Fixed dynamic semantics of `val rec` so that if `val rec` is used to
  override constructor status, then at run time, the `Bind` exception is raised
  as per rule 126 of the Definition.  So, for example, the following program
  type checks and compiles, but raises `Bind` at run time.

      val rec NONE = fn () => ()
      val _ = NONE ()

  Again, this is checked in `valrec.sml`.
  ** Added `\r\n` to ml.lex so that Windows style newlines are acceptable in
  input files.

* 2001-10-04
  ** Fixed bug in the implementation of `open` declarations, which in the case
  of `open A B` had opened `A` and then looked up `B` in the resulting
  environment.  The correct behaviour (see rule 22 of the Definition) is to
  lookup each _longstrid_ in the current environment, and then open them all in
  sequence.  This is now checked for in the `open.sml` regression test.  Thanks
  to Andreas Rossberg for pointing this bug out.
  ** Fixed bug that caused tyvars of length 1 (i.e. `'`) to be rejected.  This
  is now checked in the `id.sml` regression test.  Again, thanks to Andreas
  Rossberg for the test.

* 2001-10-02
  ** Fixed bugs in `Real.toManExp` (which always returned the wrong result
  because the call to `frexp` was not treated as side-effecting by the
  optimizer) and in `Real.minPos`, which was zero because of a mistake with
  extra precision bits.

* 2001-10-01
  ** Added `MLton.Exn.history`.
  ** Fixed register allocation bug with `fucom` instruction.  Was allowing
  `fucomp` when the first source was not removable.
  ** Changed `Real.isFinite` to use the C `math.h` `finite` function.  This
  fixed the nontermination bug which occurred in any program that used
  `Real.maxFinite`.
```

```
* 2001-09-22
  ** Bug fixes found from Ramsey's `lrtl` in `contify.fun` and
  `unused-args.fun`, both of which caused compile-time exceptions to be raised.

* 2001-09-21
  ** Fixed `MLton.World.{load,save}` so that the saved world does not store the
  max heap size.  Instead, the max heap size is computed upon load world in
  exactly the same way as at program startup.  This fixes a long-standing (but
  only recently noticed) problem in which `mlton` (which uses a saved world)
  would attempt to use as much memory as was on the machine used to build
  `world.mlton`.

* 2001-08-29
  ** Overlow checking is now on by default in the C backend.  This is a huge
  performance hit, but who cares, since we never use the C backend except for
  testing anyways.

* 2001-08-22
  ** Added support for #line directives of the form

      (*#line line.col "file"*)

  These directives only affect error messages produced by the parser and
  elaborator.

* 2001-08-17
  ** Fixed bug in RemoveUnused optimzation that caused the following program to
  fail to compile.

      fun f l = case l of [] => f l | _ :: l => f l
      val _ = f [13]

* 2001-08-14
  ** New x86-codegen infrastructure.
    *** support for tracking liveness of stack slots and carrying them in
    registers across basic blocks
    *** more specific `Entry` and `Transfer` datatypes to make calling convention
    distinctions more explicit
    *** new heuristic for carrying values in registers across basic blocks (look
    Ma, no Overflows!)
    *** new "predict" model for generating register allocation hints
    *** additional bug fixes

* 2001-08-07
  ** `MLton.Socket.shutdownWrite` flushes the outstream.


== Version 20010806

Here are the changes from version 20010706 to version 20010806.

=== Summary

* `Word.andb (w, 0xFF)` now works correctly
* `MLton.Rusage.rusage` has a patch to work around a linux kernel bug
* Programs of the form `_exp_ ; _program_` are now accepted
* Added the `MLton.Rlimit` structure
* Added the `-keep dot` flag, which produces call graphs, intraprocedural
control-flow graphs, and dominator trees

=== Details
```

```
* 2001-08-06
  ** Added simple CommonBlock elimination CPS optimization.

* 2001-08-02
  ** Took out `-keep il`.

* 2001-07-31
  ** Performance improvements to `TextIO.{input, output, output1}`.

* 2001-07-25
  ** Added RedundantTest elimination CPS optimization.

* 2001-07-21
  ** Added CommonSubexp elimination CPS optimization.

* 2001-07-20
  ** Bug fix to x86 codegen.  The `commuteBinALMD` peephole optimization would
  rewrite `mov 2,Y; add Y,Y` as `mov Y,Y; add 2,Y`.  Now the appropriate
  interference checks are made.
  ** Added intraprocedural unused argument removal.
  ** Added intraprocedural flattener.  This avoids some stupid tuple allocations
  in loops.  Decent speedup on a few benchmarks (`count-graphs`, `psdes-random`,
  `wc-scanStream`) and no noticeable slowdowns.
  ** Added `-keep dot` flag.

* 2001-07-17
  ** Modified grammar to properly handle `val rec`.  There were several problems.
    *** MLton had accepted `val rec 'a ...` instead of `val 'a rec ...`
    *** MLton had not accepted `val x = 13 and rec f = fn () => ()`
    *** MLton had not accepted `val rec rec f = fn () => ()`
    *** MLton had not accepted `val rec f = fn () => () and rec g = fn () => ()`

* 2001-07-16
  ** Workaround for Linux kernel bug that can cause `getrusage` to return a wrong
  system time value (low by one second).  See `fixedGetrusage` in `gc.c`.
  ** Bug fix to x86 codegen.  The register allocator could get confused when
  doing comparisons of floating point numbers and use the wrong operand.  The
  bug seems to have never been detected because it only happens when both of the
  operands are already on the floating point stack, which is rare, since one is
  almost always in memory since we don't carry floating point values in the
  stack across basic blocks.
  ** Added production to the grammar on page 58 of the Definition that had been
  missing from MLton since day one.

      program ::= exp ; <program>

  Also updated docs to reflect change.
  ** Modified grammar to accept the empty program.
  ** Added `-type-check` expert flag to turn on type checking in ILs.

* 2001-07-15
  ** Bug fix to the algebraic simplifier.  It had been rewriting
  `Word32.andb (w, 0wxFF)` to `w` instead of
  `Word32.andb (w, 0wxFFFFFFFF)` to `w`.

* 2001-07-13
  ** Improved CPS shrinker so that `if`-tests where the `then` and `else` branch
  jump to the same label is turned into a direct jump.
  ** Improved CPS shrinker (`Prim.apply`) to handle constructors
    *** `A = A` --> `true`
    *** `A = B` --> `false`
```

```
    *** `A x` = `B y` --> `false`
  ** Rewrote a lot of loops in the basis library to use inequalities instead of
  equality for the loop termination test so that the (forthcoming) overflow
  detection elimination will work on the loop index variable.

* 2001-07-11
  ** Fixed minor bugs in `Array2.{array,tabulate}`, `Substring.{slice}` that
  caused the `Overflow` exception to be raised instead of `Size` or `Subscript`
  ** Fixed bug in `Pack32Big.update` that caused the wrong location to be updated.
  ** Fixed several bugs in `Pack32{Big,Little}.{subArr,subVec,update}` that
  caused `Overflow` to be raised instead of `Subscript`.  Also, improved the
  implementation so that bounds checking only occurs once per call (instead of
  four times, which was sometimes happening.
  ** Fixed bugs in `Time.{toMilliseconds,toMicroseconds}` that could cause a
  spurious `Overflow` exception.
  ** Fixed bugs in `Time.{fromMilliseconds,fromMicroseconds}` that could cause a
  spurious `Time` exception.
  ** Improved `Pack32.sub*` by reordering the `orb`-s.
  ** Improved `{Int,IntInf}.mod` to increase chances of constant folding.
  ** Switched many uses of `+`, `-`, `*` in basis library to the non-overflow
  checked versions.  Modules changed were: `Array`, `Array2`, `Byte`, `Char`,
  `Int`, `IntInf`, `List`, `Pack32{Big,Little}`, `Util`, `String`, `StringCvt`,
  `Substring`, `TextIO`, `Time`, `Vector`.
  ** Added regression tests for `Array2`, `Int` (overflow checking), `Pack32`,
  `Substring`, `Time`.
  ** Changed CPS output so that it includes a dot graph for each CPS function.

* 2001-07-09
  ** Change `OS.Process.exit` so that it raises an exception if the exit status
  is not in [0, 256).
  ** Added `MLton.Rlimit` to provide access to `getrlimit` and `setrlimit`.


== Version 20010706

Here are the changes from the 20000906 version to the 20010706 version.

=== Summary

* Native X86 code generator (instead of using `gcc`)
* Significantly improved compile times
* Significantly improved run times for generated executables
* Many bug fixes
* Correct raising of the `Overflow` exception for integer arithmetic
* New modules in the `MLton` structure

=== Details

* 2001-07-06
  ** GC mods from Henry.  Mostly adding `inline` declarations.

* 2001-07-05
  ** Fixed several runtime bugs involving threads, critical sections, and
  signals.

* 2001-06-29
  ** Fixed performance bug in `cps/two-point-lattice.fun` that caused quadratic
  behavior.  This affects the raise-to-jump and useless analayses.  In
  particular, the useless analysis was blowing up when compiling `fxp`.

* 2001-06-27
  ** Henry improved `wordAlign` -- this sped up GC by 27% (during a self
```

```
  compile).

* 2001-06-20
  ** Moved `MLton.random` to `MLton.Random.rand` and added other stuff to
  `MLton.Random`
  ** Added `MLton.TextIO.mkstemp`.
  ** Made `Int.{div,quot}` respect the `-detect-overflow` switch.

* 2001-06-20
  ** Added `MLton.Syslog`.

* 2001-06-07
  ** Fixed bug in `MLton.Socket.accept` that was in the runtime implementation
  `Socket_accept`.  It did a `setsockopt SO_REUSEADDR` after the `accept`.  It
  should have been after the call to `socket` in `Socket_listen`.  Thanks to
  Doug Bagley for the fix.

* 2001-05-30
  ** Fixed bug in remove-unused that caused polymorphic equality to return
  `true` sometimes when constructors were never used in a pattern match.  For
  example, the following (in which `A` and `B` are not used as patterns):

      datatype t = A | B
      datatype u = C of t
      val _ = if C A = C B then raise Fail "bug" else ()

* 2001-03-27
  ** Fixed bug that caused all of the following to fail:
  `{LargeWord,Word,SysWord}.{toLargeInt,toLargeIntX,fromLargeInt}` The problem
  was the basis library file `integer/patch.sml` which fixed `Word32` but not
  the other structures that are the same.

* 2001-02-12
  ** Fixed bug in match compiler that caused it to spend a lot of extra time in
  deep patterns.  It still could be exponential however.  Hopefully this will
  get fixed in the release after next.  This bug could cause very slow compile
  times in some cases.  Anyways, this fix cut the `finish infer` time of a self
  compile down from 22 to under 4 seconds.  I.E. most of the time used to be
  spent due to this bug.

* 2001-02-06
  ** Fixed bug in frontend that caused the wrong file and line number to be
  reported with errors in functor bodys.

* 2001-01-03 - 2000-02-05
  ** Changes to CoreML, XML, SXML, and CPS ILs to replace lists by vectors in
  order to decrease space usage.

* 2001-01-16
  ** Fixed a bug in constant propagation where the length of vectors was not
  propagated properly.

* 2000-12-11 - 2001-01-03
  ** Major rewrite of elaborator to use a single hash table for each namespace
  instead of a hash table for every environment.

* 2000-12-20
  ** Fixed some bugs in the SML/NJ compatibility library,
  `src/lib/mlton-subs-in-smlnj`.

* 2000-12-08
  ** More careful removal of tracing code when compiling `MLton_debug=0`.  This
```

```
  cut down self compile data size by 100k and compile time by a few seconds.
  ** Added built in character and word cases propagated throughout all ILs.

* 2000-12-06
  ** Added max stack size information to `gc-summary`.

* 2000-12-05
  ** Added `src/benchmark`, which contains an SML program that benchmarks all of
  the SML compilers I have my hands on.  The script has lots of hardwired paths
  for now.

* 2000-12-04
  ** Fixed bug in `Posix.ProcEnv.environ,` which did not work correctly in a
  saved world (the original `environ` was saved).  In fact, it did not work at
  all because the ML primitive expected a constant and the C was a nullary
  function. This caused a segfault with any program using
  `Posix.ProcEnv.environ`.
  ** `Added MLton.ProcEnv.setenv`, since there doesn't seem to be any `setenv`
  in the basis library.

* 2000-11-29
  ** Changed backend so that it should no longer generate machine programs with
  `void` operands.
  ** Added `-detect-overflow` and `-safe` flags.

* 2000-11-27 - 2000-11-28
  ** Changes in many places to use `List.revMap` instead of `List.map` to cut
  down on allocation.

* 2000-11-21
  ** Added `MLton.Word.~` and `MLton.Word8.~` to the `MLton` structure.

* 2000-11-20
  ** Fixed a bug in the CPS shrinker that could cause a compile-time failure.
  It was maintaining occurrence counts incorrectly.

* 2000-11-15
  ** Fixed a (performance) bug in constant propagation that caused the hashing
  to be bad.
  ** Improved translation to XML so that the match compiler isn't called on
  tuple or if expressions.  This should speed up the translation and make the
  output smaller.
  ** Fixed a bug in the match compiler that caused it to not generate integer
  case statements.  This should speed up the mlyacc benchmark and the MLton
  front end.

* 2000-11-09
  ** Added `IntInf_equal` and `IntInf_compare` primitives.
  ** Took out the automatic `-keep c` when compiling `-g`.

* 2000-11-08
  ** Added a whole bunch of algebraic laws to the CPS shrinker, including some
  specifically targeted to `IntInf` primitives.

* 2000-11-03
  ** Improved implementation of properties so that sets don't allocate.
  ** Improved implementation of type homomorphism in type inference.  What was
  there before appears to have been a bug -- it didn't use the property on
  types.

* 2000-11-02
  ** Fixed timers used with `-v` option to use user + sys time.
```

```
* 2000-10-27
  ** Split the runtime basis library C files into many separate files so that
  only the needed code would be included by the linker.
  ** Fixed several bugs in the front end grammar and elaborator that caused type
  specifications to be handled incorrectly.  The following three programs used
  to be handled incorrectly, but are now handled correctly.

      signature S = sig type t and u = int end (* reject *)
      signature S = sig type t = int and u = t end (* accept *)
      signature S = sig eqtype t and u = int end (* reject *)

* 2000-10-25
  ** Changes to `main.sml` to run complete compiles with `-native` switch.

* 2000-10-24
  ** Removed defunctorizer.

* 2000-10-20
  ** Fixed bug in `cps-tree.fun` with `PrimExp.maySideEffect`.  This bug could
  cause `"no operand"` failures in the backend.
  ** Fixed bug in the runtime implementation of `MLton.size`.  The size for
  stack objects was using the `used` instead of `reserved`, and so was too low.

* 2000-10-19
  ** Replaced automatically generated dependencies in `src/runtime/Makefile`
  with hand generated ones.  Took out `make depend` from `src/Makefile`.  `make
  depend` was behaving really badly on RHAT 7.0.
  ** Tweaked compiler to shorten width of C output lines to work around bug in
  RHAT 7.0 `cpp` which silently truncates (very) long lines.
  ** Fixed bug in grammar that didn't allow `op` to occur in datatype and
  exception bindings, causing the following to fail

      datatype t = op T
      exception op E = op Fail

  ** Improved error messages in CM processor.  Fixed bug in CM Alias handling.

* 2000-10-18
  ** Fixed two bugs in the gc that did comparisons with `(s->limit -
  s->frontier)`, which of course doesn't work if `frontier` is beyond `limit`,
  since these are unsigned.  This could have caused segfaults, except that the
  mutator checks the `frontier` upon return from the GC.

* 2000-10-17
  ** Fixed bug in backend in the calculation of `maxFrameSize`.  It could be
  wrong (low) in some situations.
  ** Improved CPS inliner's estimate of function sizes.  The size of a function
  now takes into account other inlined functions that the function calls.  This
  also changed the meaning of the size argument to the `-inline` switch.  It now
  corresponds (roughly) to the product of the size of the function and the
  number of calls.  In general, it should be larger than before.

* 2000-10-13
  ** Made some calls to `Array.sub` unsafe in the implementation of `Array2`.
  ** Integrated Matthew's new x86 backend with floating point support.

* 2000-10-09
  ** Fixed CM file processor so that MLton works if it is run from a different
  directory than the main CM file.

* 2000-10-04
```

```
  ** Changed LimitCheck so it loops on the `frontier > limit` check.  This fixed
  a potential bug in threads caused when there is enough space available for a
  thread, `t`, before switching to another thread but not enough space when it
  resumes.  This could have caused a segfault.

* 2000-10-03
  ** More rewrites of `TextIO.StreamIO` to improve speed.
  ** Changed `TextIO` so that only `TextIO.stdErr` is unbuffered.
  ** Changed `TextIO` so that FIFOs and sockets are buffered.

* 2000-10-02
  ** Combined remove-unused-constructors, remove-unused-functions, and
  remove-unused-globals into a single pass that runs to fixed-point and produces
  results at least as good as running the previous three in (any) sequence.

* 2000-09-29
  ** Added `GC_FIRST_CHECK`, which does a gc at each limit check the first time
  it reached.
  ** Reimplemented `TextIO.StreamIO` (from 2000-09-12) to use lists of strings
  instead of lists of characters so that the per char space overhead is small.

* 2000-09-21
  ** Fixed bug in profiling labels in C code.  The label was always the basic
  block label instead of the cps function label.
  ** Added `-b` switch to `mlprof` to gather data at the basic block level.
  ** Improved performance of `TextIO.input1` by about 3X.

* 2000-09-15 - 2000-09-19
  ** Added overflow exceptions to CPS and Machine ILs.

* 2000-09-12
  ** Fixed `TextIO.scanStream`.  It was very broken.
  ** Added `TextIO.{getInstream,mkInstream,setInstream}` and
  `TextIO.StreamIO.{canInput,closeIn,endOfStream,input1,input,inputAll,inputLine,inputN}`.

* 2000-09-11
  ** Fixed `Real_qequal` in `mlton-lib.h`.  It was missing a paren that caused
  code using it to not even compile.  It was also semantically incorrect.
  ** Noted that `Real_{equal,lt,le,gt,ge}` may not follow basis library spec,
  since ANSI does not require IEEE compliance, and hence these could return
  wrong results when nans are involved.


== Version 20000906

Here are the changes from the 20000712 version to the 20000906 version.

=== Summary

* Version 20000906 is mostly a bugfix release over 20000712.  The other major
changes are that `mllex` and `mlyacc` are now included and that `mlton` can now
process a limited subset of CM files as input.

=== Details

* 2000-09-06
  ** Fixed `Socket_listen` in `mlton-lib.c` so that it closes the socket if the
  `bind`, `listen`, or `getsockname` fails.  This could have caused a file
  descriptor leak.

* 2000-09-05
  ** Added `-static` commandline switch.
```

```
  ** Changed default max heap size to .85 RAM from .95 RAM.
  ** Added `PackRealLittle` structure to basis library.

* 2000-08-25
  ** Added cases on integers to ILs (instead of using sequences of tests) so
  that backend can emit more efficient test (jump table, binary tree, ...).

* 2000-08-24
  ** Fixed bug in `gc.c`.  `dfsInitializeStack` would `smummap` a `NULL` pointer
  whenver `toSpace` was `NULL`.  This could cause `MLton.size` to segfault.
  ** Fixed bug in `Popt` that caused `-k` to fail with no keeps.

* 2000-08-22 - 2000-08-23
  ** Ported `mllex` and `mlyacc` from SML/NJ

* 2000-08-20 - 2000-08-21
  ** Added ability to use a `.cm` file as input to MLton.

* 2000-08-16
  ** Ported `mlprof` to SML.
  ** Fixed bug in `library/basic/assert.sml` that caused asserts to be run even
  when `MLton.debug = false`.

* 2000-08-15
  ** Fixed bug in backend -- computation of `maxFrameSize` was wrong.  It didn't
  count slots in frames that didn't make nontail calls.  This could lead to the
  stack being overwritten because a stack limit check didn't guarantee enough
  space, and lead to a segfault.
  ** Fixed bug in `gc.c` `newThreadOfSize`.  If the thread allocation caused a
  gc, then the stack wasn't forwarded, leading to a segfault.  The solution was
  to ensure enough memory all at once, and then fill in both objects.

* 2000-08-14
  ** Changed limit checks so that checks < 512 bytes are replaced by a check for
  0 bytes.  The runtime also moves the limit down by 512.  This is done so that
  the common case, a small limit check, has less code and is faster.
  ** Fixed bug in `cps/cps-tree.fun`. `Program.hasPrim` returned `true` for any
  program that had *any* primapp, not just programs satisfying the predicate.
  This caused `cps/once.fun` to be overly conservative, since it thought that
  every program used continuations.

* 2000-08-10
  ** Fixed bug in CPS typechecker.  It didn't enforce that handlers should be
  defined before any reference to them -- including implicit references in
  `HandlerPops`.  This caused an evil bug in the liveness analysis where a
  variable that was only live in the handler was missed in a continuation
  because the liveness for the handler wasn't computed yet.
  ** Limited the size for moving up limit checks for arrays whose size is known
  at compile time to avoid huge limit checks getting moved into loops.
  ** added `-indent`, `-kp`, `-show-types` switches.
  ** Put optimization in CPS IL suggested by Neal Glew.  It determines for each
  toplevel function if it can raise an exception to its caller.  Also, it
  removes `HanderPush` and `HandlerPop` for handlers that are not on top of the
  stack for any nontail call.

* 2000-08-08
  ** Changed register allocator so that continuation formals can be allocated in
  pseudo registers -- they aren't necessarily forced to the stack.

* 2000-08-03
  ** Fixed bug in constant folding.  `Word8.>>` had been used to implement
  `Word8.~>>`.
```

```
  ** Fixed bug in allocate registers that was not forcing the size argument to
  `Primitive.Array.array` to be a stack slot.  This could cause problems if
  there was a thread switch in the limit check, since upon return the size
  pseudo register would have a bogus value.

* 2000-08-01
  ** Turned back on XML simplification after monomorphisation.

* 2000-07-31
  ** Fixed bug in `MLton.Itimer.set` that caused the time to be doubled.
  ** Fixed bug in `MLton.Thread` that made it look like asynchronous exceptions
  were allowed by `throw`-ing an exception raising thunk to an interrupted
  thread obtained via a signal handler.  Attempting asynchronous exceptions will
  now cause process death, with a helpful error message.

* 2000-07-27
  ** Updated docs to include `structure World: MLTON_WORLD` in `MLton`
  structure.
  ** Added toplevel signatures `MLTON_{CONT, ..., WORLD}` to basis library.
  ** Fixed broken link in docs to CM in `cmcat` section.

* 2000-07-26
  ** Eliminated `GC_switchToThread` and `Thread_switchTo1`, since the inlined
  version `Thread_switchTo` is all that's needed, and Matt's X86 backend now
  handles it.
  ** Added `MLton.Signal.vtalrm`, needed for `Itimer.Set{which =
  Itimer.Virtual, ...}`.

* 2000-07-25
  ** Added `MLton.Socket.shutdownWrite`.

* 2000-07-21
  ** Updated `mlton-lib.c` `MLton_bug` with new email (MLton@sourcelight.com).

* 2000-07-19
  ** Fixed `Posix.Process.kill` to check for errors.

* 2000-07-18
  ** Fixed the following `Posix.ProcEnv` functions to check for errors:
  `setgid`, `setpgid`, `setsid`, `setuid`.
  ** Fixed `doc/examples/callcc.sml`.


== Version 20000712

Here are the changes from the 1999-07-12 to the 20000712 version.

=== Details

* 2000-06-10 - 2000-07-12
  ** Too many changes to count: bug fixes, new basis library modules, optimizer
  improvements.

* 2000-06-30
  ** Fixed bug in monomorphiser that caused programs with non-value carrying
  exception declarations in polymorphic functions to have a compile-time error
  because of a duplicate label.  The problem was that the exception constructor
  wasn't duplicated.

* 2000-05-22 - 2000-06-10
  ** Finished the changes for the new CPS IL.
```

```
* 2000-01-01
  ** Fixed some errors in the basis library:
    *** `Real.copySign`
    *** `Posix.FileSys.fpathconf`
    *** `Posix.IO.{lseek, getlk, setlk, setlkw}`
    *** `Posix.ProcEnv.setpgid`
    *** `Posix.TTY.getattr`
    *** `System.FileSys.realPath`

* 1999-12-22
  ** Fixed bug in `src/closure-convert/abstract-value.fun` that caused a
  compiler failure whenever a program had a vector where the element type
  contained an `->`.

* 1999-12-10
  ** Changed dead code elimination in `core-ml/dead-code.fun` so that wildcard
  declarations (`val _ = ...`) in the basis are kept.  Changed places in the
  basis library to take advantage of this.
  ** Added `setTopLevelHander` primitive so that the basis library code can
  define the toplevel handler.
  ** Changed `basis-library/misc/suffix.sml` to call `OS.Process.exit`.  Took
  out `Halt` transfer from CPS, since the program never should reach it.
  ** Cleaned up `basis-library/system/{process.sml, unix.sml}` to use the new
  signal handling stuff.

* 1999-11-28 - 1999-12-20
  ** Added support for threads and cleaned up signal handling.  This involved a
  number of changes:
    *** The stack is now allocated as just another kind of heap object.
    *** Limit checks are inserted at all loop headers, whether or not there is
    any allocation.  This is to ensure that the signal handler always has a
    chance to get called.
    *** The register allocator puts more variables in stack slots.  The new rule
    is that a variable goes in a stack slot if it is ever live across a nontail
    call, in a handler, or (this is the new part) across a limit check.
    *** Arguments are passed on the stack, with the convention determined by
    argument types.
    *** The "locals" array of pointers that was copied to/from for GC is now
    gone, because no registers (in particular no pointer valued registers) can
    be live at a limit check point.

* 1999-11-21
  ** Runtime system
    *** Fixed a bug introduced by the signal code (presumably on 1999-08-09)
    that caused a gc to *not* be performed when doing a save world.  This caused
    the heaps created by save world to be the same size as the heap -- not the
    live data.  This was quite bad.
    *** Cleaned up the `Makefile`.  Add make depend.
    *** Added max gc pause to `gc-summary` info.
    *** Move heap translation variables that had been file statics into the
    `GC_state`.
  ** Made `structure Position` available at toplevel.
  ** Basis Library
    *** Added `MLton.loadWorld`
  ** Added `Primitive.usesCallcc`
  ** Added `Primitive.safe`
  ** Removed special size functions from `cps/save-world` -- they are no longer
  necessary since size doesn't do a gc.
  ** Fixed another (sigh) bug in `cps/simplify-types.fun` that could cause it to
  not terminate.

* 1999-11-16
```

```
  ** Cleaned up `backend/machine.fun` a bit so that it spits out macros for
  allocation of objects and bumping of frontier.  Added macros `MLTON_object`
  and `MLTON_incFrontier` to `include/mlton-lib.h`.
  ** Fixed a bug in `backend/limit-check.fun` that caused loops to not be
  detected if they were only reached by a case branch.  This could cause there
  to be loop that allocates with no limit check.  Needless to say, this could
  cause a segfault if the loop ran for long enough.

* 1999-10-18
  ** Added basis library function `Array2.copy`.

* 1999-08-15
  ** Turned off globalization of ref cells (`closure-convert/globalize.fun`)
  because it interacts badly with serialization.

* 1999-08-13
  ** Fixed bug in `mlton-lib.h` in `MLTON_allocArrayNoPointers` that was
  triggered when `bytesPerElt == 0`.  The problem was that it wasn't reserving
  space for the forwarding pointer.  This could cause a segfault.

* 1999-08-08 and 1999-08-09
  ** Added support for signal handling.

* 1999-08-07
  ** Fixed bugs in `Array.tabulate` (and other `tabulate` variants) caused if
  the function argument used `callcc`.

* 1999-08-01
  ** Added serialization, which was mostly code in `src/runtime/gc.c`. +
  `GC_serialize` converts an object to a `Word8Vector.vector`. +
  `GC_deserialize` undoes the conversion. + (de)Serialization should work for
  all objects except for functions, because I haven't yet added the support in
  the flow analysis.

* 1999-07-31
  ** Cleaned up the GC.  Changed headers, by stealing a bit from the number of
  non pointers and making it a mark bit (used in `GC_size`).
  ** Rewrote `GC_size` so that it runs in time proportional to the number of
  pointers in the object.  It does a depth-first-search now, using toSpace to
  hold the stack.

* 1999-07-30
  ** Fixed bug in `SUBSTRING`.  `getc` had the wrong type.  This bug wasn't
  noticed because MLton doesn't do enough type checking.
  ** Fixed bug (segfault) caused when a GC immediately followed a throw.

* 1999-07-29
  ** Fixed bug in `Date.fmt` (`basis-library/system/date.sml`).  It was not
  setting `Tm.buf`, and hence the time was always 0 unless there had been a
  previous call to `setTmBuf`.

* 1999-07-28
  ** Fixed bugs in `Posix.IO.FLock.{getlk,setlk,setlkw}`, which would cause
  compilation to fail because `FLock.toInt` was defined as the C `castInt`,
  which no longer exists.  Instead, expand `FLock.toInt` to
  `MLTON_pointerToInt`, which was added to `include/mlton-lib.h`.
  ** Changed `Posix.Primitive.Flock` to `Posix.Primitive.FLock`.
  ** Added `MLTON_chown`, `MLTON_ftruncate` to `include/mlton-posix.h`.  They
  were missing.  This would cause compilation of any program using
  `Posix.FileSys.{chown,ftruncate}` to fail.  Also made it so all of the
  primitives in `basis-library/posix/primitive.sml` use `MLTON_` versions of
  functions, even if a wrapper is unnecessary.
```

```
* 1999-07-25
  ** Added some other missing signature definitions to toplevel.

* 1999-07-24
  ** Added missing `OS_*` signature definitions to
  `basis-library/top-level/top-level.sml`.

* 1999-07-19
  ** Fixed bug in `basis-library/arrays-and-vectors/mono-array.sml`.  Used `:>`
  instead of `:` so that the monomorphic array types are abstract.


== Version 19990712

Here are the changes from the 1999-03-19 version to the 1999-07-12 version.

=== Details

* 1999-07-12
  ** Changed `src/backend/machine.fun` so that the 'pointer locals' array is
  only as large as neccessary in order to copy all pointer-valued locals, not as
  large as the number of pointer-valued locals.

* 1999-07-11
  ** Rewrote `src/backend/allocate-registers.fun` so that it does a better job
  of sharing "registers" (i.e. C local variables) and stack slots.  This should
  cut down on the amount of copying that has to happen before and after a gc.
  It should also cut down on the size of stack slots.

* 1999-07-10
  ** Fixed a bug in `src/backend/parallel-move.fun` that should have been
  triggered on most any parallel move.  I guess parallel moves almost never
  happened due to the old register allocation strategy -- but, with the new one
  (see note for 1999-07-12) parallel moves will be frequent.

* 1999-06-27
  ** Fixed `src/main.sml` so that when compiling `-p`, the `.c` file is compiled
  `-g` and the `.o` is linked `-p`.
  ** In `bakend/machine.fun`, added profiling comments before chunkswitches and
  put in an optimization to avoid printing repeated profiling comments.  Also,
  profiling comments are only output when compiling `-p`.

* 1999-06-17
  ** Changed `-i` to `-inline`, `-f` to `-flatten`, `-np` to `-no-polyvariance`,
  `-u` to `-unsafe`.
  ** Added `-i`, `-I`, `-l`, `-L` flags for includes and libraries.
  ** Updated documentation for these options and for ffi.

* 1999-06-16
  ** Hardwired version number in `src/control/control.sml`.  As it stood, the
  version number was computed when MLton was built after someone downloaded it,
  which was clearly wrong.

* 1999-06-16
  ** Fixed undefined variable `time` in `GC_done` in `src/runtime/gc.c`.

* 19990-06-08
  ** in `include/mlton-lib.h`:
    *** removed `#include <huge_val.h>`
    *** added `#include <math.h>`
    *** and deleted all of the function signatures I had copied from `math.h`
```

```
  ** Changed `Real.{minNormalPos, minPos, maxFinite}` so that they are computed
  in `real.sml` instead of appearing as constants in the C.

* 1999-06-07
  `IntInf.pow` added to basis library.

* 1999-06-04
  ** `bin/mlton` changed to use `.arch-n-opsys` if it exists.

* 1999-06-03
  ** `src/Makefile` changed to use `sml-cm` instead of `sml`

* 1999-05-10
  ** Patch to `src/atoms/small-int-inf.fun` to work around a bug in the SML/NJ
  implementation of bignums.  This bug was causing some hex bignum constants to
  be lexed incorrectly.

* 1999-04-15
  ** Comments emitted in C code for profiling.  The comments identify the CPS
  function responsible for each C statement.

* 1999-04-15
  **  `callcc` and `throw` added.

* 1999-04-15
  ** Bug in `src/cps/simplify-types` fixed.  The bug caused nontermination
  whenever there was a circular datatype with a vector on the rhs.
  E.g. `datatype t = T of t vector`


== Version 19990319

Here are the changes from the 1998-08-26 version to the 1999-03-19 version.

=== Summary

* Compile time and code size have decreased.
* Runtime performance of executables has improved.
* Large programs can now be compiled.
* MLton is self hosting.
* The basis library is mostly complete and many bugs have been fixed.
* The monomorphiser (`-m`) is no longer available.
* The heap and stack are automatically resized.
* There are now facilities for heap checkpointing (`MLton.saveWorld`) and object
size computation (`MLton.size`).
* MLton uses the GNU multiprecision (GnuMP) library to provide a fast
implementation of `IntInf`.
```

ChrisClearwater

Chunkify

Chunkify is an analysis pass for the RSSA IntermediateLanguage, invoked from ToMachine.

Description

It partitions all the labels (function and block) in an RSSA program into disjoint sets, referred to as chunks.

Implementation

- `chunkify.sig`
- `chunkify.fun`

Details and Notes

Breaking large RSSA functions into chunks is necessary for reasonable compile times with the CCodegen and the LLVMCodegen.

CKitLibrary

The ckit Library is a C front end written in SML that translates C source code (after preprocessing) into abstract syntax represented as a set of SML datatypes. The ckit Library is distributed with SML/NJ. Due to differences between SML/NJ and MLton, this library will not work out-of-the box with MLton.

As of 20180119, MLton includes a port of the ckit Library synchronized with SML/NJ version 110.82.

Usage

- You can import the ckit Library into an MLB file with:

MLB file	Description
`$(SML_LIB)/ckit-lib/ckit-lib.mlb`	

- If you are porting a project from SML/NJ's CompilationManager to MLton's ML Basis system using `cm2mlb`, note that the following map is included by default:

```
# ckit Library
$ckit-lib.cm                              $(SML_LIB)/ckit-lib
$ckit-lib.cm/ckit-lib.cm                  $(SML_LIB)/ckit-lib/ckit-lib.mlb
```

  This will automatically convert a `$/ckit-lib.cm` import in an input `.cm` file into a `$(SML_LIB)/ckit-lib/ckit-lib.mlb` import in the output `.mlb` file.

Details

The following changes were made to the ckit Library, in addition to deriving the `.mlb` file from the `.cm` file:

- `ast/pp/pp-ast-adornment-sig.sml` (modified): Rewrote use of `signature` in `local`.
- `ast/pp/pp-ast-ext-sig.sml` (modified): Rewrote use of `signature` in `local`.
- `ast/type-util-sig.sml` (modified): Rewrote use of `signature` in `local`.
- `parser/parse-tree-sig.sml` (modified): Rewrote use of (sequential) `withtype` in signature.
- `parser/parse-tree.sml` (modified): Rewrote use of (sequential) `withtype`.

Patch

- `ckit.patch`

Closure

A closure is a data structure that is the run-time representation of a function.

Typical Implementation

In a typical implementation, a closure consists of a *code pointer* (indicating what the function does) and an *environment* containing the values of the free variables of the function. For example, in the expression

```
let
   val x = 5
in
   fn y => x + y
end
```

the closure for `fn y => x + y` contains a pointer to a piece of code that knows to take its argument and add the value of `x` to it, plus the environment recording the value of `x` as `5`.

To call a function, the code pointer is extracted and jumped to, passing in some agreed upon location the environment and the argument.

MLton's Implementation

MLton does not implement closures traditionally. Instead, based on whole-program higher-order control-flow analysis, MLton represents a function as an element of a sum type, where the variant indicates which function it is and carries the free variables as arguments. See ClosureConvert and CejtinEtAl00 for details.

ClosureConvert

ClosureConvert is a translation pass from the SXML IntermediateLanguage to the SSA IntermediateLanguage.

Description

It converts an SXML program into an SSA program.

Defunctionalization is the technique used to eliminate Closures (see CejtinEtAl00).

Uses Globalize and LambdaFree analyses.

Implementation

- `closure-convert.sig`
- `closure-convert.fun`

Details and Notes

CMinusMinus

C-- is a portable assembly language intended to make it easy for compilers for different high-level languages to share the same backend. An experimental version of MLton has been made to generate C--.

- http://www.mlton.org/pipermail/mlton/2005-March/026850.html

Also see

- LLVM

Codegen

Codegen is a translation pass from the Machine IntermediateLanguage to one or more compilation units that can be compiled to native object code by an external tool.

Implementation

- `codegen`

Details and Notes

The following codegens are implemented:

- AMD64Codegen
- CCodegen
- LLVMCodegen
- X86Codegen

CombineConversions

CombineConversions is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

This pass looks for and simplifies nested calls to (signed) extension/truncation.

Implementation

- `combine-conversions.fun`

Details and Notes

It processes each block in dfs order (visiting definitions before uses):

- If the statement is not a `PrimApp` with `Word_extdToWord`, skip it.
- After processing a conversion, it tags the `Var` for subsequent use.
- When inspecting a conversion, check if the `Var` operand is also the result of a conversion. If it is, try to combine the two operations. Repeatedly simplify until hitting either a non-conversion `Var` or a case where the conversion cannot be simplified.

The optimization rules are very simple:

```
x1 = ...
x2 = Word_extdToWord (W1, W2, {signed=s1}) x1
x3 = Word_extdToWord (W2, W3, {signed=s2}) x2
```

- If `W1 =W2`, then there is no conversions before `x_1`.

  This is guaranteed because `W2 =W3` will always trigger optimization.

- Case `W1 <=W3 <=W2`:

  ```
  x3 = Word_extdToWord (W1, W3, {signed=s1}) x1
  ```

- Case `W1 < W2 < W3 AND ((NOT s1) OR s2)`:

  ```
  x3 = Word_extdToWord (W1, W3, {signed=s1}) x1
  ```

- Case `W1 =W2 < W3`:

  unoptimized, because there are no conversions past `W1` and `x2 =x1`

- Case `W3 <=W2 <=W1 OR W3 <=W1 <=W2`:

  ```
  x_3 = Word_extdToWord (W1, W3, {signed=_}) x1
  ```

  because `W3 <=W1 && W3 <=W2`, just clip `x1`

- Case `W2 < W1 <=W3 OR W2 < W3 <=W1`:

  unoptimized, because `W2 < W1 && W2 < W3`, has truncation effect

- Case `W1 < W2 < W3 AND (s1 AND (NOT s2))`:

  unoptimized, because each conversion affects the result separately

CommonArg

CommonArg is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

It optimizes instances of `Goto` transfers that pass the same arguments to the same label; e.g.

```
L_1 ()
  ...
  z1 = ?
  ...
  L_3 (x, y, z1)
L_2 ()
  ...
  z2 = ?
  ...
  L_3 (x, y, z2)
L_3 (a, b, c)
  ...
```

This code can be simplified to:

```
L_1 ()
  ...
  z1 = ?
  ...
  L_3 (z1)
L_2 ()
  ...
  z2 = ?
  ...
  L_3 (z2)
L_3 (c)
  a = x
  b = y
```

which saves a number of resources: time of setting up the arguments for the jump to `L_3`, space (either stack or pseudo-registers) for the arguments of `L_3`, etc. It may also expose some other optimizations, if more information is known about `x` or `y`.

Implementation

- `common-arg.fun`

Details and Notes

Three analyses were originally proposed to drive the optimization transformation. Only the *Dominator Analysis* is currently implemented. (Implementations of the other analyses are available in the repository history.)

Syntactic Analysis

The simplest analysis I could think of maintains

```
varInfo: Var.t -> Var.t option list ref
```

initialized to `[]`.

- For each variable `v` bound in a `Statement.t` or in the `Function.t` args, then `List.push(varInfo v, NONE)`.
- For each `L (x1, ..., xn)` transfer where `(a1, ..., an)` are the formals of `L`, then `List.push(varInfo ai, SOME xi)`.
- For each block argument a used in an unknown context (e.g., arguments of blocks used as continuations, handlers, arith success, runtime return, or case switch labels), then `List.push(varInfo a, NONE)`.

Now, any block argument `a` such that `varInfo a =xs`, where all of the elements of `xs` are equal to `SOME x`, can be optimized by setting `a =x` at the beginning of the block and dropping the argument from `Goto` transfers.

That takes care of the example above. We can clearly do slightly better, by changing the transformation criteria to the following: any block argument a such that `varInfo a =xs`, where all of the elements of `xs` are equal to `SOME x` *or* are equal to `SOME a`, can be optimized by setting `a =x` at the beginning of the block and dropping the argument from `Goto` transfers. This optimizes a case like:

```
L_1 ()
  ... z1 = ? ...
  L_3 (x, y, z1)
L_2 ()
  ... z2 = ? ...
  L_3(x, y, z2)
L_3 (a, b, c)
  ... w = ? ...
  case w of
    true => L_4 | false => L_5
L_4 ()
   ...
   L_3 (a, b, w)
L_5 ()
   ...
```

where a common argument is passed to a loop (and is invariant through the loop). Of course, the LoopInvariant optimization pass would normally introduce a local loop and essentially reduce this to the first example, but I have seen this in practice, which suggests that some optimizations after LoopInvariant do enough simplifications to introduce (new) loop invariant arguments.

Fixpoint Analysis

However, the above analysis and transformation doesn't cover the cases where eliminating one common argument exposes the opportunity to eliminate other common arguments. For example:

```
L_1 ()
  ...
  L_3 (x)
L_2 ()
  ...
  L_3 (x)
L_3 (a)
  ...
  L_5 (a)
L_4 ()
  ...
  L_5 (x)
L_5 (b)
  ...
```

One pass of analysis and transformation would eliminate the argument to `L_3` and rewrite the `L_5(a)` transfer to `L_5 (x)`, thereby exposing the opportunity to eliminate the common argument to `L_5`.

The interdependency the arguments to `L_3` and `L_5` suggest performing some sort of fixed-point analysis. This analysis is relatively simple; maintain

```
varInfo: Var.t -> VarLattice.t
```

where

```
VarLattice.t ~=~ Bot | Point of Var.t | Top
```

(but is implemented by the FlatLattice functor with a `lessThan` list and `value ref` under the hood), initialized to `Bot`.

- For each variable `v` bound in a `Statement.t` or in the `Function.t` args, then `VarLattice.<=(Point v, varInfo v)`
- For each `L (x1, ..., xn)` transfer where `(a1, ..., an)` are the formals of `L`}, then `VarLattice.<=(varInfo xi, varInfo ai).`
- For each block argument a used in an unknown context, then `VarLattice.<=(Point a, varInfo a).`

Now, any block argument a such that `varInfo a =Point x` can be optimized by setting `a =x` at the beginning of the block and dropping the argument from `Goto` transfers.

Now, with the last example, we introduce the ordering constraints:

```
varInfo x <= varInfo a
varInfo a <= varInfo b
varInfo x <= varInfo b
```

Assuming that `varInfo x =Point x`, then we get `varInfo a =Point x` and `varInfo b =Point x`, and we optimize the example as desired.

But, that is a rather weak assumption. It's quite possible for `varInfo x =Top`. For example, consider:

```
G_1 ()
  ... n = 1 ...
  L_0 (n)
G_2 ()
  ... m = 2 ...
  L_0 (m)
L_0 (x)
  ...
L_1 ()
  ...
  L_3 (x)
L_2 ()
  ...
  L_3 (x)
L_3 (a)
  ...
  L_5(a)
L_4 ()
  ...
  L_5(x)
L_5 (b)
   ...
```

Now `varInfo x =varInfo a =varInfo b =Top`. What went wrong here? When `varInfo x` went to `Top`, it got propagated all the way through to `a` and `b`, and prevented the elimination of any common arguments. What we'd like to do instead is when `varInfo x` goes to `Top`, propagate on `Point x` — we have no hope of eliminating `x`, but if we hold `x` constant, then we have a chance of eliminating arguments for which `x` is passed as an actual.

Dominator Analysis

Does anyone see where this is going yet? Pausing for a little thought, MatthewFluet realized that he had once before tried proposing this kind of "fix" to a fixed-point analysis — when we were first investigating the Contify optimization in light of John Reppy's CWS paper. Of course, that "fix" failed because it defined a non-monotonic function and one couldn't take the fixed point. But, StephenWeeks suggested a dominator based approach, and we were able to show that, indeed, the dominator analysis subsumed both the previous call based analysis and the cont based analysis. And, a moment's reflection reveals further parallels: when `varInfo:Var.t -> Var.t option list ref`, we have something analogous to the call analysis, and when `varInfo:Var.t -> VarLattice.t`, we have something analogous to the cont analysis. Maybe there is something analogous to the dominator approach (and therefore superior to the previous analyses).

And this turns out to be the case. Construct the graph `G` as follows:

```
nodes(G) = {Root} U Var.t
edges(G) = {Root -> v | v bound in a Statement.t or
                                in the Function.t args} U
           {xi -> ai | L(x1, ..., xn) transfer where (a1, ..., an)
                                      are the formals of L} U
           {Root -> a | a is a block argument used in an unknown context}
```

Let `idom(x)` be the immediate dominator of `x` in `G` with root `Root`. Now, any block argument a such that `idom(a) =x <> Root` can be optimized by setting `a =x` at the beginning of the block and dropping the argument from `Goto` transfers.

Furthermore, experimental evidence suggests (and we are confident that a formal presentation could prove) that the dominator analysis subsumes the "syntactic" and "fixpoint" based analyses in this context as well and that the dominator analysis gets "everything" in one go.

Final Thoughts

I must admit, I was rather surprised at this progression and final result. At the outset, I never would have thought of a connection between Contify and CommonArg optimizations. They would seem to be two completely different optimizations. Although, this may not really be the case. As one of the reviewers of the ICFP paper said:

> I understand that such a form of CPS might be convenient in some cases, but when we're talking about analyzing code to detect that some continuation is constant, I think it makes a lot more sense to make all the continuation arguments completely explicit.
>
> I believe that making all the continuation arguments explicit will show that the optimization can be generalized to eliminating constant arguments, whether continuations or not.

What I think the common argument optimization shows is that the dominator analysis does slightly better than the reviewer puts it: we find more than just constant continuations, we find common continuations. And I think this is further justified by the fact that I have observed common argument eliminate some `env_X` arguments which would appear to correspond to determining that while the closure being executed isn't constant it is at least the same as the closure being passed elsewhere.

At first, I was curious whether or not we had missed a bigger picture with the dominator analysis. When we wrote the contification paper, I assumed that the dominator analysis was a specialized solution to a specialized problem; we never suggested that it was a technique suited to a larger class of analyses. After initially finding a connection between Contify and CommonArg (and thinking that the only connection was the technique), I wondered if the dominator technique really was applicable to a larger class of analyses. That is still a question, but after writing up the above, I'm suspecting that the "real story" is that the dominator analysis is a solution to the common argument optimization, and that the Contify optimization is specializing CommonArg to the case of continuation arguments (with a different transformation at the end). (Note, a whole-program, inter-procedural common argument analysis doesn't really make sense (in our SSA IntermediateLanguage), because the only way of passing values between functions is as arguments. (Unless of course in the case that the common argument is also a constant argument, in which case ConstantPropagation could lift it to a global.) The inter-procedural Contify optimization works out because there we move the function to the argument.)

Anyways, it's still unclear to me whether or not the dominator based approach solves other kinds of problems.

Phase Ordering

On the downside, the optimization doesn't have a huge impact on runtime, although it does predictably saved some code size. I stuck it in the optimization sequence after Flatten and (the third round of) LocalFlatten, since it seems to me that we could have cases where some components of a tuple used as an argument are common, but the whole tuple isn't. I think it makes sense to add it after IntroduceLoops and LoopInvariant (even though CommonArg get some things that LoopInvariant gets, it doesn't get all of them). I also think that it makes sense to add it before CommonSubexp, since identifying variables could expose more common subexpressions. I would think a similar thought applies to RedundantTests.

CommonBlock

CommonBlock is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

It eliminates equivalent blocks in a SSA function. The equivalence criteria requires blocks to have no arguments or statements and transfer via `Raise`, `Return`, or `Goto` of a single global variable.

Implementation

- `common-block.fun`

Details and Notes

- Rewrites

  ```
  L_X ()
    raise (global_Y)
  ```

  to

  ```
  L_X ()
    L_Y' ()
  ```

  and adds

  ```
  L_Y' ()
    raise (global_Y)
  ```

  to the SSA function.

- Rewrites

  ```
  L_X ()
    return (global_Y)
  ```

  to

  ```
  L_X ()
    L_Y' ()
  ```

  and adds

  ```
  L_Y' ()
    return (global_Y)
  ```

  to the SSA function.

- Rewrites

  ```
  L_X ()
    L_Z (global_Y)
  ```

  to

  ```
  L_X ()
    L_Y' ()
  ```

and adds

```
L_Y' ()
  L_Z (global_Y)
```

to the SSA function.

The Shrink pass rewrites all uses of `L_X` to `L_Y'` and drops `L_X`.

For example, all uncaught `Overflow` exceptions in a SSA function share the same raising block.

CommonSubexp

CommonSubexp is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

It eliminates instances of common subexpressions.

Implementation

- `common-subexp.fun`

Details and Notes

In addition to getting the usual sorts of things like

- ```
  (w + 0wx1) + (w + 0wx1)
  ```

  rewritten to

  ```
  let val w' = w + 0wx1 in w' + w' end
  ```

it also gets things like

- ```
  val a = Array_uninit n
  val b = Array_length a
  ```

  rewritten to

  ```
  val a = Array_uninit n
  val b = n
  ```

`Arith` transfers are handled specially. The *result* of an `Arith` transfer can be used in *common* `Arith` transfers that it dominates:

- ```
  val l = (n + m) + (n + m)

  val k = (l + n) + ((l + m) handle Overflow => ((l + m)
                                              handle Overflow => l + n))
  ```

  is rewritten so that `(n + m)` is computed exactly once, as are `(l + n)` and `(l + m)`.
  ```

CompilationManager

The Compilation Manager (CM) is SML/NJ's mechanism for supporting programming-in-the-very-large.

Porting SML/NJ CM files to MLton

To help in porting CM files to MLton, the MLton source distribution includes the sources for a utility, `cm2mlb`, that will print an ML Basis file with essentially the same semantics as the CM file — handling the full syntax of CM supported by your installed SML/NJ version and correctly handling export filters. When `cm2mlb` encounters a `.cm` import, it attempts to convert it to a corresponding `.mlb` import. CM anchored paths are translated to paths according to a default configuration file (`cm2mlb-map`). For example, the default configuration includes

```
# Standard ML Basis Library
$SMLNJ-BASIS                            $(SML_LIB)/basis
$basis.cm                               $(SML_LIB)/basis
$basis.cm/basis.cm                      $(SML_LIB)/basis/basis.mlb
```

to ensure that a `$/basis.cm` import is translated to a `$(SML_LIB)/basis/basis.mlb` import. See `util/cm2mlb` for details. Building `cm2mlb` requires that you have already installed a recent version of SML/NJ.

CompilerOverview

The following table shows the overall structure of the compiler. IntermediateLanguages are shown in the center column. The names of compiler passes are listed in the left and right columns.

Compiler Overview		
Translation Passes	*IntermediateLanguage*	*Optimization Passes*
	Source	
FrontEnd		
	AST	
Elaborate		
	CoreML	CoreMLSimplify
Defunctorize		
	XML	XMLSimplify
Monomorphise		
	SXML	SXMLSimplify
ClosureConvert		
	SSA	SSASimplify
ToSSA2		
	SSA2	SSA2Simplify
ToRSSA		
	RSSA	RSSASimplify
ToMachine		
	Machine	
Codegen		

The `Compile` functor (`compile.sig`, `compile.fun`), controls the high-level view of the compiler passes, from FrontEnd to code generation.

CompilerPassTemplate

An analysis pass for the ZZZ IntermediateLanguage, invoked from ZZZOtherPass. An implementation pass for the ZZZ IntermediateLanguage, invoked from ZZZSimplify. An optimization pass for the ZZZ IntermediateLanguage, invoked from ZZZSimplify. A rewrite pass for the ZZZ IntermediateLanguage, invoked from ZZZOtherPass. A translation pass from the ZZA IntermediateLanguage to the ZZB IntermediateLanguage.

Description

A short description of the pass.

Implementation

- `ZZZ.fun`

Details and Notes

Relevant details and notes.

CompileTimeOptions

MLton's compile-time options control the name of the output file, the verbosity of compile-time messages, and whether or not certain optimizations are performed. They also can specify which intermediate files are saved and can stop the compilation process early, at some intermediate pass, in which case compilation can be resumed by passing the generated files to MLton. MLton uses the input file suffix to determine the type of input program. The possibilities are `.c`, `.mlb`, `.o`, `.s`, and `.sml`.

With no arguments, MLton prints the version number and exits. For a usage message, run MLton with an invalid switch, e.g. `mlton -z`. In the explanation below and in the usage message, for flags that take a number of choices (e.g. `{true|false}`), the first value listed is the default.

Options

- `-align n`

  Aligns object in memory by the specified alignment (`4` or `8`). The default varies depending on architecture.

- `-as-opt option`

  Pass *option* to `gcc` when compiling assembler code. If you wish to pass an option to the assembler, you must use `gcc`'s `-Wa,` syntax.

- `-cc-opt option`

  Pass *option* to `gcc` when compiling C code.

- `-codegen {native|amd64|c|llvm|x86}`

  Generate native object code via amd64 assembly, C code, LLVM code, or x86 code or C code. With `-codegen native` (`-codegen amd64` or `-codegen x86`), MLton typically compiles more quickly and generates better code.

- `-const name value`

  Set the value of a compile-time constant. Here is a list of available constants, their default values, and what they control.

  - `Exn.keepHistory {false|true}`
    Enable `MLton.Exn.history`. See MLtonExn for details. There is a performance cost to setting this to `true`, both in memory usage of exceptions and in run time, because of additional work that must be performed at each exception construction, raise, and handle.

- `-default-ann ann`

  Specify default ML Basis annotations. For example, `-default-ann 'warnUnused true'` causes unused variable warnings to be enabled by default. A default is overridden by the corresponding annotation in an ML Basis file.

- `-default-type type`

  Specify the default binding for a primitive type. For example, `-default-type word64` causes the top-level type `word` and the top-level structure `Word` in the Basis Library to be equal to `Word64.word` and `Word64:WORD`, respectively. Similarly, `-default-type intinf` causes the top-level type `int` and the top-level structure `Int` in the Basis Library to be equal to `IntInf.int` and `IntInf:INTEGER`, respectively.

- `-disable-ann ann`

  Ignore the specified ML Basis annotation in every ML Basis file. For example, to see *all* match and unused warnings, compile with

  ```
  -default-ann 'warnUnused true'
  -disable-ann forceUsed
  -disable-ann nonexhaustiveMatch
  -disable-ann redundantMatch
  -disable-ann warnUnused
  ```

- `-export-header file`

  Write C prototypes to *file* for all of the functions in the program exported from SML to C.

- `-ieee-fp {false|true}`

  Cause the x86 native code generator to be pedantic about following the IEEE floating point standard. By default, it is not, because of the performance cost. This only has an effect with `-codegen x86`.

- `-inline` *n*

  Set the inlining threshold used in the optimizer. The threshold is an approximate measure of code size of a procedure. The default is `320`.

- `-keep {g|o}`

  Save intermediate files. If no `-keep` argument is given, then only the output file is saved.

`g`	generated `.c` and `.s` files passed to `gcc` and generated `.ll` files passed to `llvm-as`
`o`	object (`.o`) files

- `-link-opt` *option*

  Pass *option* to `gcc` when linking. You can use this to specify library search paths, e.g. `-link-opt -Lpath`, and libraries to link with, e.g., `-link-opt -lfoo`, or even both at the same time, e.g. `-link-opt '-Lpath -lfoo'`. If you wish to pass an option to the linker, you must use `gcc`'s `-Wl,` syntax, e.g., `-link-opt '-Wl,--export-dynamic'`.

- `-llvm-as-opt` *option*

  Pass *option* to `llvm-as` when assembling (`.ll` to `.bc`) LLVM code.

- `-llvm-llc-opt` *option*

  Pass *option* to `llc` when compiling (`.bc` to `.o`) LLVM code.

- `-llvm-opt-opt` *option*

  Pass *option* to `opt` when optimizing (`.bc` to `.bc`) LLVM code.

- `-mlb-path-map` *file*

  Use *file* as an ML Basis path map to define additional MLB path variables. Multiple uses of `-mlb-path-map` and `-mlb-path-var` are allowed, with variable definitions in later path maps taking precedence over earlier ones.

- `-mlb-path-var` *name value*

  Define an additional MLB path variable. Multiple uses of `-mlb-path-map` and `-mlb-path-var` are allowed, with variable definitions in later path maps taking precedence over earlier ones.

- `-output` *file*

  Specify the name of the final output file. The default name is the input file name with its suffix removed and an appropriate, possibly empty, suffix added.

- `-profile {no|alloc|count|time}`

  Produce an executable that gathers profiling data. When such an executable is run, it produces an `mlmon.out` file.

- `-profile-branch {false|true}`

  If true, the profiler will separately gather profiling data for each branch of a function definition, `case` expression, and `if` expression.

- `-profile-stack {false|true}`

  If `true`, the executable will gather profiling data for all functions on the stack, not just the currently executing function. See ProfilingTheStack.

- `-profile-val {false|true}`

  If `true`, the profiler will separately gather profiling data for each (expansive) `val` declaration.

- `-runtime arg`

  Pass argument to the runtime system via `@MLton`. See RunTimeOptions. The argument will be processed before other `@MLton` command line switches. Multiple uses of `-runtime` are allowed, and will pass all the arguments in order. If the same runtime switch occurs more than once, then the last setting will take effect. There is no need to supply the leading `@MLton` or the trailing `--`; these will be supplied automatically.

  An argument to `-runtime` may contain spaces, which will cause the argument to be treated as a sequence of words by the runtime. For example the command line:

  ```
  mlton -runtime 'ram-slop 0.4' foo.sml
  ```

  will cause `foo` to run as if it had been called like:

  ```
  foo @MLton ram-slop 0.4 --
  ```

  An executable created with `-runtime stop` doesn't process any `@MLton` arguments. This is useful to create an executable, e.g., `echo`, that must treat `@MLton` like any other command-line argument.

  ```
  % mlton -runtime stop echo.sml
  % echo @MLton --
  @MLton --
  ```

- `-show-basis file`

  Pretty print to *file* the basis defined by the input program. See ShowBasis.

- `-show-def-use file`

  Output def-use information to *file*. Each identifier that is defined appears on a line, followed on subsequent lines by the position of each use.

- `-stop {f|g|o|tc}`

  Specify when to stop.

`f`	list of files on stdout (only makes sense when input is `foo.mlb`)
`g`	generated `.c` and `.s` files
`o`	object (`.o`) files
`tc`	after type checking

  If you compile with `-stop g` or `-stop o`, you can resume compilation by running MLton on the generated `.c` and `.s` or `.o` files.

- `-target {self|...}`

  Generate an executable that runs on the specified platform. The default is `self`, which means to compile for the machine that MLton is running on. To use any other target, you must first install a cross compiler.

- `-target-as-opt target option`

  Like `-as-opt`, this passes *option* to `gcc` when compliling assembler code, except it only passes *option* when the target architecture, operating system, or arch-os pair is *target*.

- `-target-cc-opt target option`

  Like `-cc-opt`, this passes *option* to `gcc` when compiling C code, except it only passes *option* when the target architecture, operating system, or arch-os pair is *target*.

- `-target-link-opt target option`

  Like `-link-opt`, this passes *option* to `gcc` when linking, except it only passes *option* when the target architecture, operating system, or arch-os pair is *target*.

- `-verbose {0|1|2|3}`

  How verbose to be about what passes are running. The default is `0`.

0	silent
1	calls to compiler, assembler, and linker
2	1, plus intermediate compiler passes
3	2, plus some data structure sizes

CompilingWithSMLNJ

You can compile MLton with SML/NJ, however the resulting compiler will run much more slowly than MLton compiled by itself. We don't recommend using SML/NJ as a means of porting MLton to a new platform or bootstrapping on a new platform.

If you do want to build MLton with SML/NJ, it is best to have a binary MLton package installed. If you don't, here are some issues you may encounter when you run `make smlnj-mlton`.

You will get (many copies of) the error messages:

```
/bin/sh: mlton: command not found
```

and

```
make[2]: mlton: Command not found
```

The `Makefile` calls `mlton` to determine dependencies, and can proceed in spite of this error.

If you don't have an `mllex` executable, you will get the error message:

```
mllex: Command not found
```

Building MLton requires `mllex` and `mlyacc` executables, which are distributed with a binary package of MLton. The easiest solution is to copy the front-end lexer/parser files from a different machine (`ml.grm.sml`, `ml.grm.sig`, `ml.lex.sml`, `mlb.grm.sig`, `mlb.grm.sml`).

ConcurrentML

Concurrent ML is an SML concurrency library based on synchronous message passing. MLton has an initial port of CML from SML/NJ, but is missing a thread-safe wrapper around the Basis Library and event-based equivalents to `IO` and `OS` functions.

All of the core CML functionality is present.

```
structure CML: CML
structure SyncVar: SYNC_VAR
structure Mailbox: MAILBOX
structure Multicast: MULTICAST
structure SimpleRPC: SIMPLE_RPC
structure RunCML: RUN_CML
```

The `RUN_CML` signature is minimal.

```
signature RUN_CML =
   sig
      val isRunning: unit -> bool
      val doit: (unit -> unit) * Time.time option -> OS.Process.status
      val shutdown: OS.Process.status -> 'a
   end
```

MLton's `RunCML` structure does not include all of the cleanup and logging operations of SML/NJ's `RunCML` structure. However, the implementation does include the `CML.timeOutEvt` and `CML.atTimeEvt` functions, and a preemptive scheduler that knows to sleep when there are no ready threads and some threads blocked on time events.

Because MLton does not wrap the Basis Library for CML, the "right" way to call a Basis Library function that is stateful is to wrap the call with `MLton.Thread.atomically`.

Usage

- You can import the CML Library into an MLB file with:

MLB file	Description
`$(SML_LIB)/cml/cml.mlb`	

- If you are porting a project from SML/NJ's CompilationManager to MLton's ML Basis system using `cm2mlb`, note that the following map is included by default:

```
# CML Library
$cml                                    $(SML_LIB)/cml
$cml/cml.cm                             $(SML_LIB)/cml/cml.mlb
```

  This will automatically convert a `$cml/cml.cm` import in an input `.cm` file into a `$(SML_LIB)/cml/cml.mlb` import in the output `.mlb` file.

Also see

- ConcurrentMLImplementation
- eXene

ConcurrentMLImplementation

Here are some notes on MLton's implementation of ConcurrentML.

Concurrent ML was originally implemented for SML/NJ. It was ported to MLton in the summer of 2004. The main difference between the implementations is that SML/NJ uses continuations to implement CML threads, while MLton uses its underlying thread package. Presently, MLton's threads are a little more heavyweight than SML/NJ's continuations, but it's pretty clear that there is some fat there that could be trimmed.

The implementation of CML in SML/NJ is built upon the first-class continuations of the `SMLofNJ.Cont` module.

```
type 'a cont
val callcc: ('a cont -> 'a) -> 'a
val isolate: ('a -> unit) -> 'a cont
val throw: 'a cont -> 'a -> 'b
```

The implementation of CML in MLton is built upon the first-class threads of the MLtonThread module.

```
type 'a t
val new: ('a -> unit) -> 'a t
val prepare: 'a t * 'a -> Runnable.t
val switch: ('a t -> Runnable.t) -> 'a
```

The port is relatively straightforward, because CML always throws to a continuation at most once. Hence, an "abstract" implementation of CML could be built upon first-class one-shot continuations, which map equally well to SML/NJ's continuations and MLton's threads.

The "essence" of the port is to transform:

```
callcc (fn k => ... throw k' v')
```

to

```
switch (fn t => ... prepare (t', v'))
```

which suffices for the vast majority of the CML implementation.

There was only one complicated transformation: blocking multiple base events. In SML/NJ CML, the representation of base events is given by:

```
datatype 'a event_status
  = ENABLED of {prio: int, doFn: unit -> 'a}
  | BLOCKED of {
        transId: trans_id ref,
        cleanUp: unit -> unit,
        next: unit -> unit
      } -> 'a
type 'a base_evt = unit -> 'a event_status
```

When synchronizing on a set of base events, which are all blocked, we must invoke each `BLOCKED` function with the same `transId` and `cleanUp` (the `transId` is (checked and) set to `CANCEL` by the `cleanUp` function, which is invoked by the first enabled event; this "fizzles" every other event in the synchronization group that later becomes enabled). However, each `BLOCKED` function is implemented by a callcc, so that when the event is enabled, it throws back to the point of synchronization. Hence, the next function (which doesn't return) is invoked by the `BLOCKED` function to escape the callcc and continue in the thread performing the synchronization. In SML/NJ this is implemented as follows:

```
fun ext ([], blockFns) = callcc (fn k => let
      val throw = throw k
      val (transId, setFlg) = mkFlg()
      fun log [] = S.atomicDispatch ()
        | log (blockFn:: r) =
            throw (blockFn {
```

```
                transId = transId,
                cleanUp = setFlg,
                next = fn () => log r
              })
      in
        log blockFns; error "[log]"
      end)
```

(Note that `S.atomicDispatch` invokes the continuation of the next continuation on the ready queue.) This doesn't map well to the MLton thread model. Although it follows the

```
callcc (fn k => ... throw k v)
```

model, the fact that `blockFn` will also attempt to do

```
callcc (fn k' => ... next ())
```

means that the naive transformation will result in nested `switch`-es.

We need to think a little more about what this code is trying to do. Essentially, each `blockFn` wants to capture this continuation, hold on to it until the event is enabled, and continue with next; when the event is enabled, before invoking the continuation and returning to the synchronization point, the `cleanUp` and other event specific operations are performed.

To accomplish the same effect in the MLton thread implementation, we have the following:

```
datatype 'a status =
   ENABLED of {prio: int, doitFn: unit -> 'a}
 | BLOCKED of {transId: trans_id,
               cleanUp: unit -> unit,
               next: unit -> rdy_thread} -> 'a

type 'a base = unit -> 'a status

fun ext ([], blockFns): 'a =
     S.atomicSwitch
     (fn (t: 'a S.thread) =>
      let
         val (transId, cleanUp) = TransID.mkFlg ()
         fun log blockFns: S.rdy_thread =
            case blockFns of
               [] => S.next ()
             | blockFn::blockFns =>
                  (S.prep o S.new)
                  (fn _ => fn () =>
                   let
                      val () = S.atomicBegin ()
                      val x = blockFn {transId = transId,
                                       cleanUp = cleanUp,
                                       next = fn () => log blockFns}
                   in S.switch(fn _ => S.prepVal (t, x))
                   end)
      in
         log blockFns
      end)
```

To avoid the nested `switch`-es, I run the `blockFn` in it's own thread, whose only purpose is to return to the synchronization point. This corresponds to the `throw (blockFn {...})` in the SML/NJ implementation. I'm worried that this implementation might be a little expensive, starting a new thread for each blocked event (when there are only multiple blocked events in a synchronization group). But, I don't see another way of implementing this behavior in the MLton thread model.

Note that another way of thinking about what is going on is to consider each `blockFn` as prepending a different set of actions to the thread `t`. It might be possible to give a `MLton.Thread.unsafePrepend`.

```
fun unsafePrepend (T r: 'a t, f: 'b -> 'a): 'b t =
   let
      val t =
         case !r of
            Dead => raise Fail "prepend to a Dead thread"
          | New g => New (g o f)
          | Paused (g, t) => Paused (fn h => g (f o h), t)
   in (* r := Dead; *)
      T (ref t)
   end
```

I have commented out the `r :=Dead`, which would allow multiple prepends to the same thread (i.e., not destroying the original thread in the process). Of course, only one of the threads could be run: if the original thread were in the `Paused` state, then multiple threads would share the underlying runtime/primitive thread. Now, this matches the "one-shot" nature of CML continuations/threads, but I'm not comfortable with extending `MLton.Thread` with such an unsafe operation.

Other than this complication with blocking multiple base events, the port was quite routine. (As a very pleasant surprise, the CML implementation in SML/NJ doesn't use any SML/NJ-isms.) There is a slight difference in the way in which critical sections are handled in SML/NJ and MLton; since `MLton.Thread.switch` *always* leaves a critical section, it is sometimes necessary to add additional `atomicBegin`-s/`atomicEnd`-s to ensure that we remain in a critical section after a thread switch.

While looking at virtually every file in the core CML implementation, I took the liberty of simplifying things where it seemed possible; in terms of style, the implementation is about half-way between Reppy's original and MLton's.

Some changes of note:

- `util/` contains all pertinent data-structures: (functional and imperative) queues, (functional) priority queues. Hence, it should be easier to switch in more efficient or real-time implementations.
- `core-cml/scheduler.sml`: in both implementations, this is where most of the interesting action takes place. I've made the connection between `MLton.Thread.t`-s and `ThreadId.thread_id`-s more abstract than it is in the SML/NJ implementation, and encapsulated all of the `MLton.Thread` operations in this module.
- eliminated all of the "by hand" inlining

Future Extensions

The CML documentation says the following:

```
CML.joinEvt: thread_id -> unit event
```

- `joinEvt tid`
  creates an event value for synchronizing on the termination of the thread with the ID tid. There are three ways that a thread may terminate: the function that was passed to spawn (or spawnc) may return; it may call the exit function, or it may have an uncaught exception. Note that `joinEvt` does not distinguish between these cases; it also does not become enabled if the named thread deadlocks (even if it is garbage collected).

I believe that the `MLton.Finalizable` might be able to relax that last restriction. Upon the creation of a `'a Scheduler.thread`, we could attach a finalizer to the underlying `'a MLton.Thread.t` that enables the `joinEvt` (in the associated `ThreadID.thread_id`) when the `'a MLton.Thread.t` becomes unreachable.

I don't know why CML doesn't have

```
CML.kill: thread_id -> unit
```

which has a fairly simple implementation — setting a kill flag in the `thread_id` and adjusting the scheduler to discard any killed threads that it takes off the ready queue. The fairness of the scheduler ensures that a killed thread will eventually be discarded. The semantics are little murky for blocked threads that are killed, though. For example, consider a thread blocked on

SyncVar.mTake mv and a thread blocked on SyncVar.mGet mv. If the first thread is killed while blocked, and a third thread does SyncVar.mPut (mv, x), then we might expect that we'll enable the second thread, and never the first. But, when only the ready queue is able to discard killed threads, then the SyncVar.mPut could enable the first thread (putting it on the ready queue, from which it will be discarded) and leave the second thread blocked. We could solve this by adjusting the TransID.trans_id types and the "cleaner" functions to look for both canceled transactions and transactions on killed threads.

John Reppy says that MarlowEtAl01 and FlattFindler04 explain why CML.kill would be a bad idea.

Between CML.timeOutEvt and CML.kill, one could give an efficient solution to the recent comp.lang.ml post about terminating a function that doesn't complete in a given time.

```
fun timeOut (f: unit -> 'a, t: Time.time): 'a option =
  let
     val iv = SyncVar.iVar ()
     val tid = CML.spawn (fn () => SyncVar.iPut (iv, f ()))
  in
     CML.select
     [CML.wrap (CML.timeOutEvt t, fn () => (CML.kill tid; NONE)),
      CML.wrap (SyncVar.iGetEvt iv, fn x => SOME x)]
  end
```

Space Safety

There are some CML related posts on the MLton mailing list:

- http://www.mlton.org/pipermail/mlton/2004-May/

that discuss concerns that SML/NJ's implementation is not space efficient, because multi-shot continuations can be held indefinitely on event queues. MLton is better off because of the one-shot nature — when an event enables a thread, all other copies of the thread waiting in other event queues get turned into dead threads (of zero size).

ConstantPropagation

ConstantPropagation is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

This is whole-program constant propagation, even through data structures. It also performs globalization of (small) values computed once.

Uses Multi.

Implementation

- `constant-propagation.fun`

Details and Notes

Contact

Mailing lists

There are three mailing lists available.

- `MLton-user@mlton.org`
  MLton user community discussion
  - subscribe archive (SourceForge; current), archive (PiperMail; through 201110)
- `MLton-devel@mlton.org`
  MLton developer community discussion
  - subscribe archive (SourceForge; current), archive (PiperMail; through 201110)
- `MLton-commit@mlton.org`
  MLton code commits
  - subscribe
  - archive (SourceForge; current), archive (PiperMail; through 201110)

Mailing list policies

- Both mailing lists are unmoderated. However, the mailing lists are configured to discard all spam, to hold all non-subscriber posts for moderation, to accept all subscriber posts, and to admin approve subscription requests. Please contact Matthew Fluet if it appears that your messages are being discarded as spam.
- Large messages (over 256K) should not be sent. Rather, please send an email containing the discussion text and a link to any large files.
- Discussions started on the mailing lists should stay on the mailing lists. Private replies may be bounced to the mailing list for the benefit of those following the discussion.
- Discussions started on `MLton-user@mlton.org` may be migrated to `MLton-devel@mlton.org`, particularly when the discussion shifts from how to use MLton to how to modify MLton (e.g., to fix a bug identified by the initial discussion).

IRC

- Some MLton developers and users are in channel `#sml` on http://freenode.net.

Contify

Contify is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

Contification is a compiler optimization that turns a function that always returns to the same place into a continuation. This exposes control-flow information that is required by many optimizations, including traditional loop optimizations.

Implementation

- `contify.fun`

Details and Notes

See Contification Using Dominators. The intermediate language described in that paper has since evolved to the SSA IntermediateLanguage; hence, the complication described in Section 6.1 is no longer relevant.

CoreML

Core ML is an IntermediateLanguage, translated from AST by Elaborate, optimized by CoreMLSimplify, and translated by Defunctorize to XML.

Description

CoreML is polymorphic, higher-order, and has nested patterns.

Implementation

- `core-ml.sig`
- `core-ml.fun`

Type Checking

The CoreML IntermediateLanguage has no independent type checker.

Details and Notes

CoreMLSimplify

The single optimization pass for the CoreML IntermediateLanguage is controlled by the `Compile` functor (`compile.fun`).

The following optimization pass is implemented:

- DeadCode

Credits

MLton was designed and implemented by HenryCejtin, MatthewFluet, SureshJagannathan, and StephenWeeks.

- HenryCejtin wrote the IntInf implementation, the original profiler, the original man pages, the .spec files for the RPMs, and lots of little hacks to speed stuff up.
- MatthewFluet implemented the X86 and AMD64 native code generators, ported mlprof to work with the native code generator, did a lot of work on the SSA optimizer, both adding new optimizations and improving or porting existing optimizations, updated the Basis Library implementation, ported ConcurrentML and ML-NLFFI to MLton, implemented the ML Basis system, ported MLton to 64-bit platforms, and currently leads the project.
- SureshJagannathan implemented some early inlining and uncurrying optimizations.
- StephenWeeks implemented most of the original version of MLton, and continues to keep his fingers in most every part.

Many people have helped us over the years. Here is an alphabetical list.

- JesperLouisAndersen sent several patches to improve the runtime on FreeBSD and ported MLton to run on NetBSD and OpenBSD.
- JohnnyAndersen implemented BinIO, modified MLton so it could cross compile to MinGW, and provided useful discussion about cross-compilation.
- Alexander Abushkevich extended support for OpenBSD.
- Ross Bayer added the -keep ast compile-time option and experimented with porting the build system to CMake.
- Kevin Bradley added initial support for SuccessorML features.
- Bryan Camp added -disable-pass _regex_ and enable-pass _regex_ compile options to generalize -drop-pass _regex_ and added Array_copyArray and Array_copyVector primitives.
- Jason Carr added a parser combinator library and a parser for the SXML IR, extended compilation to start with a .sxml file, and experimented with alternate control-flow analyses for closure conversion.
- Christopher Cramer contributed support for additional Posix.ProcEnv.sysconf variables, performance improvements for String.concatWith, and Debian packaging.
- Alain Deutsch and PolySpace Technologies provided many bug fixes and runtime system improvements, code to help the Sparc/Solaris port, and funded a number of improvements to MLton.
- Armando Doval updated mlnlffigen to warn and skip functions with struct/union arguments.
- Martin Elsman provided helpful discussions in the development of the ML Basis system.
- Brent Fulgham ported MLton most of the way to MinGW.
- AdamGoode provided a script to build the PDF MLton Guide and maintains the Fedora packages.
- Simon Helsen provided bug reports, suggestions, and helpful discussions.
- Joe Hurd provided useful discussion and feedback on source-level profiling.
- VesaKarvonen contributed esml-mode.el and esml-mlb-mode.el (see Emacs), contributed patches for improving match warnings, contributed esml-du-mlton.el and extended def-use output to include types of variable definitions (see EmacsDefUseMode), and improved constant folding of floating-point operations.
- Richard Kelsey provided helpful discussions.
- Ville Laurikari ported MLton to IA64/HPUX, HPPA/HPUX, PowerPC/AIX, PowerPC64/AIX.
- Brian Leibig implemented the LLVMCodegen.

- Geoffrey Mainland helped with FreeBSD packaging.
- Eric McCorkle ported MLton to Intel Mac.
- TomMurphy wrote the original version of `MLton.Syslog` as part of his `mlftpd` project, and has sent many useful bug reports and suggestions.
- Michael Neumann helped to patch the runtime to compile under FreeBSD.
- Barak Pearlmutter built the original Debian package for MLton, and helped us to take over the process.
- Filip Pizlo ported MLton to (PowerPC) Darwin.
- Vedant Raiththa extended the ForeignFunctionInterface with support for `pure` and `impure` attributes to `_import`.
- Krishna Ravikumar added initial support for vector expressions and the `Vector_vector` primitive.
- John Reppy assisted in porting MLton to Intel Mac.
- Sam Rushing ported MLton to FreeBSD.
- Rob Simmons refactored the array and vector implementation in the Basis Library: into a primitive implementation (using `SeqInt.int` for indexing) and a wrapper implementation (using the default `Int.int` for indexing).
- Jeffrey Mark Siskind provided helpful discussions and inspiration with his Stalin Scheme compiler.
- Matthew Surawski added LoopUnroll and LoopUnswitch SSA optimizations.
- WesleyTerpstra added support for `MLton.Process.create`, made a number of contributions to the ForeignFunctionInterface, contributed a number of runtime system patches, added support for compiling to a C library, ported MLton to MinGW and all Debian supported architectures with cross-compiling support, and maintains the Debian and MinGW packages.
- Maksim Yegorov added rudimentary support for `./configure` and other improvements to the build system and implemented the ShareZeroVec SSA optimization.
- Luke Ziarek assisted in porting MLton to (PowerPC) Darwin.

We have also benefited from other software development tools and used code from other sources.

- MLton was developed using Standard ML of New Jersey and the Compilation Manager (CM)
- MLton's lexer (`mlton/frontend/ml.lex`), parser (`mlton/frontend/ml.grm`), and precedence-parser (`mlton/elaborate/precedence-parse.fun`) are modified versions of code from SML/NJ.
- The MLton Basis Library implementation of conversions between binary and decimal representations of reals uses David Gay's gdtoa library.
- The MLton Basis Library implementation uses modified versions of portions of the the SML/NJ Basis Library implementation modules `OS.IO`, `Posix.IO`, `Process`, and `Unix`.
- The MLton Basis Library implementation uses modified versions of portions of the ML Kit Version 4.1.4 Basis Library implementation modules `Path`, `Time`, and `Date`.
- Many of the benchmarks come from the SML/NJ benchmark suite.
- Many of the regression tests come from the ML Kit Version 4.1.4 distribution, which borrowed them from the Moscow ML distribution.
- MLton uses the GNU multiprecision library for its implementation of `IntInf`.
- MLton's implementation of mllex, mlyacc, the ckit Library, the ML-LPT Library, the MLRISC Library, the SML/NJ Library, Concurrent ML, mlnlffigen and ML-NLFFI are modified versions of code from SML/NJ.

CrossCompiling

MLton's `-target` flag directs MLton to cross compile an application for another platform. By default, MLton is only able to compile for the machine it is running on. In order to use MLton as a cross compiler, you need to do two things.

1. Install the GCC cross-compiler tools on the host so that GCC can compile to the target.
2. Cross compile the MLton runtime system to build the runtime libraries for the target.

To make the terminology clear, we refer to the *host* as the machine MLton is running on and the *target* as the machine that MLton is compiling for.

To build a GCC cross-compiler toolset on the host, you can use the script `bin/build-cross-gcc`, available in the MLton sources, as a template. The value of the `target` variable in that script is important, since that is what you will pass to MLton's `-target` flag. Once you have the toolset built, you should be able to test it by cross compiling a simple hello world program on your host machine.

```
% gcc -b i386-pc-cygwin -o hello-world hello-world.c
```

You should now be able to run `hello-world` on the target machine, in this case, a Cygwin machine.

Next, you must cross compile the MLton runtime system and inform MLton of the availability of the new target. The script `bin/add-cross` from the MLton sources will help you do this. Please read the comments at the top of the script. Here is a sample run adding a Solaris cross compiler.

```
% add-cross sparc-sun-solaris sun blade
Making runtime.
Building print-constants executable.
Running print-constants on blade.
```

Running `add-cross` uses `ssh` to compile the runtime on the target machine and to create `print-constants`, which prints out all of the constants that MLton needs in order to implement the Basis Library. The script runs `print-constants` on the target machine (`blade` in this case), and saves the output.

Once you have done all this, you should be able to cross compile SML applications. For example,

```
mlton -target i386-pc-cygwin hello-world.sml
```

will create `hello-world`, which you should be able to run from a Cygwin shell on your Windows machine.

Cross-compiling alternatives

Building and maintaining cross-compiling `gcc`'s is complex. You may find it simpler to use `mlton -keep g` to generate the files on the host, then copy the files to the target, and then use `gcc` or `mlton` on the target to compile the files.

CVS

CVS (Concurrent Versions System) is a version control system. The MLton project used CVS to maintain its source code, but switched to Subversion on 20050730.

Here are some online CVS resources.

- Open Source Development with CVS

DeadCode

DeadCode is an optimization pass for the CoreML IntermediateLanguage, invoked from CoreMLSimplify.

Description

This pass eliminates declarations from the Basis Library not needed by the user program.

Implementation

- `dead-code.sig`
- `dead-code.fun`

Details and Notes

In order to compile small programs rapidly, a pass of dead code elimination is run in order to eliminate as much of the Basis Library as possible. The dead code elimination algorithm used is not safe in general, and only works because the Basis Library implementation has special properties:

- it terminates
- it performs no I/O

The dead code elimination includes the minimal set of declarations from the Basis Library so that there are no free variables in the user program (or remaining Basis Library implementation). It has a special hack to include all bindings of the form:

```
val _ = ...
```

There is an ML Basis annotation, `deadCode true`, that governs which code is subject to this unsafe dead-code elimination.

DeepFlatten

DeepFlatten is an optimization pass for the SSA2 IntermediateLanguage, invoked from SSA2Simplify.

Description

This pass flattens into mutable fields of objects and into vectors.

For example, an `(int * int) ref` is represented by a 2 word object, and an `(int * int) array` contains pairs of `int`-s, rather than pointers to pairs of `int`-s.

Implementation

- `deep-flatten.fun`

Details and Notes

There are some performance issues with the deep flatten pass, where it consumes an excessive amount of memory.

- http://www.mlton.org/pipermail/mlton/2005-April/026990.html
- http://www.mlton.org/pipermail/mlton-user/2010-June/001626.html
- http://www.mlton.org/pipermail/mlton/2010-December/030876.html

A number of applications require compilation with `-disable-pass deepFlatten` to avoid exceeding available memory. It is often asked whether the deep flatten pass usually has a significant impact on performance. The standard benchmark suite was run with and without the deep flatten pass enabled when the pass was first introduced:

- http://www.mlton.org/pipermail/mlton/2004-August/025760.html

The conclusion is that it does not have a significant impact. However, these are micro benchmarks; other applications may derive greater benefit from the pass.

DefineTypeBeforeUse

Standard ML requires types to be defined before they are used. Because of type inference, the use of a type can be implicit; hence, this requirement is more subtle than it might appear. For example, the following program is not type correct, because the type of `r` is `t option ref`, but `t` is defined after `r`.

```
val r = ref NONE
datatype t = A | B
val () = r := SOME A
```

MLton reports the following error, indicating that the type defined on line 2 is used on line 1.

```
Error: z.sml 3.10-3.20.
  Function applied to incorrect argument.
    expects: _ * [???] option
    but got: _ * [t] option
    in: := (r, SOME A)
    note: type would escape its scope: t
    escape from: z.sml 2.10-2.10
    escape to: z.sml 1.1-1.16
Warning: z.sml 1.5-1.5.
  Type of variable was not inferred and could not be generalized: r.
    type: ??? option ref
    in: val r = ref NONE
```

While the above example is benign, the following example shows how to cast an integer to a function by (implicitly) using a type before it is defined. In the example, the ref cell `r` is of type `t option ref`, where `t` is defined *after* `r`, as a parameter to functor `F`.

```
val r = ref NONE
functor F (type t
           val x: t) =
   struct
      val () = r := SOME x
      fun get () = valOf (!r)
   end
structure S1 = F (type t = unit -> unit
                  val x = fn () => ())
structure S2 = F (type t = int
                  val x = 13)
val () = S1.get () ()
```

MLton reports the following error.

```
Warning: z.sml 1.5-1.5.
  Type of variable was not inferred and could not be generalized: r.
    type: ??? option ref
    in: val r = ref NONE
Error: z.sml 5.16-5.26.
  Function applied to incorrect argument.
    expects: _ * [???] option
    but got: _ * [t] option
    in: := (r, SOME x)
    note: type would escape its scope: t
    escape from: z.sml 2.17-2.17
    escape to: z.sml 1.1-1.16
Warning: z.sml 6.11-6.13.
  Type of variable was not inferred and could not be generalized: get.
    type: unit -> ???
    in: fun get () = (valOf (! r))
Error: z.sml 12.10-12.18.
```

```
Function not of arrow type.
  function: [unit]
  in: (S1.get ()) ()
```

DefinitionOfStandardML

The Definition of Standard ML (Revised) is a terse and formal specification of Standard ML's syntax and semantics. The language specified by this book is often referred to as SML 97. You can check its syntax grammar online (thanks to Andreas Rossberg).

The Definition of Standard ML is an older version of the definition, published in 1990. The accompanying Commentary introduces and explains the notation and approach. The same notation is used in the SML 97 definition, so it is worth keeping the older definition and its commentary at hand if you intend a close study of the definition.

Defunctorize

Defunctorize is a translation pass from the CoreML IntermediateLanguage to the XML IntermediateLanguage.

Description

This pass converts a CoreML program to an XML program by performing:

- linearization
- MatchCompile
- polymorphic `val` dec expansion
- `datatype` lifting (to the top-level)

Implementation

- `defunctorize.sig`
- `defunctorize.fun`

Details and Notes

This pass is grossly misnamed and does not perform defunctorization.

Datatype Lifting

This pass moves all `datatype` declarations to the top level.

Standard ML `datatype` declarations can contain type variables that are not bound in the declaration itself. For example, the following program is valid.

```
fun 'a f (x: 'a) =
   let
      datatype 'b t = T of 'a * 'b
      val y: int t = T (x, 1)
   in
      13
   end
```

Unfortunately, the `datatype` declaration can not be immediately moved to the top level, because that would leave `'a` free.

```
datatype 'b t = T of 'a * 'b
fun 'a f (x: 'a) =
   let
      val y: int t = T (x, 1)
   in
      13
   end
```

In order to safely move `datatype`s, this pass must close them, as well as add any free type variables as extra arguments to the type constructor. For example, the above program would be translated to the following.

```
datatype ('a, 'b) t = T of 'a * 'b
fun 'a f (x: 'a) =
   let
      val y: ('a * int) t = T (x, 1)
   in
      13
   end
```

Historical Notes

The Defunctorize pass originally eliminated Standard ML functors by duplicating their body at each application. These duties have been adopted by the Elaborate pass.

Developers

Here is a picture of the MLton team at a meeting in Chicago in August 2003. From left to right we have:

StephenWeeks — MatthewFluet — HenryCejtin — SureshJagannathan

Also see the Credits for a list of specific contributions.

Developers list

A number of people read the developers mailing list, `MLton-devel@mlton.org`, and make contributions there. Here's a list of those who have a page here.

- AndreiFormiga
- JesperLouisAndersen
- JohnnyAndersen
- MichaelNorrish
- MikeThomas
- RayRacine
- WesleyTerpstra
- VesaKarvonen

Development

This page is the central point for MLton development.

- Access the Sources.
- Check the current `CHANGELOG.adoc` or recent commits.
- Open Issues.
- Ideas for Projects to improve MLton.
- Developers that are or have been involved in the project.

Notes

- CompilerOverview
- CompilingWithSMLNJ
- CrossCompiling
- License
- NeedsReview
- PortingMLton
- ReleaseChecklist
- SelfCompiling

Documentation

Documentation is available on the following topics.

- Standard ML
  - Basis Library
  - Additional libraries
- Installing MLton
- Using MLton
  - Foreign function interface (FFI)
  - Manual page (compile-time options run-time options)
  - ML Basis system
  - MLton structure
  - Platform-specific notes
  - Profiling
  - Type checking
  - Help for porting from SML/NJ to MLton.
- About MLton
  - Credits
  - Drawbacks
  - Features
  - History
  - License
  - Talk
  - WishList
- Tools
  - MLLex (`mllex.pdf`)
  - MLYacc (`mlyacc.pdf`)
  - MLNLFFIGen (`mlyacc.pdf`)
- References

Drawbacks

MLton has several drawbacks due to its use of whole-program compilation.

- Large compile-time memory requirement.

  Because MLton performs whole-program analysis and optimization, compilation requires a large amount of memory. For example, compiling MLton (over 140K lines) requires at least 512M RAM.

- Long compile times.

  Whole-program compilation can take a long time. For example, compiling MLton (over 140K lines) on a 1.6GHz machine takes five to ten minutes.

- No interactive top level.

  Because of whole-program compilation, MLton does not provide an interactive top level. In particular, it does not implement the optional Basis Library function `use`.

Eclipse

Eclipse is an open, extensible IDE.

ML-Dev is a plug-in for Eclipse, based on SML/NJ.

There has been some talk on the MLton mailing list about adding support to Eclipse for MLton/SML, and in particular, using http://eclipsefp.sourceforge.net/. We are unaware of any progress along those lines.

Elaborate

Elaborate is a translation pass from the AST IntermediateLanguage to the CoreML IntermediateLanguage.

Description

This pass performs type inference and type checking according to the Definition. It also defunctorizes the program, eliminating all module-level constructs.

Implementation

- `elaborate.sig`
- `elaborate.fun`
- `elaborate-env.sig`
- `elaborate-env.fun`
- `elaborate-modules.sig`
- `elaborate-modules.fun`
- `elaborate-core.sig`
- `elaborate-core.fun`
- `elaborate`

Details and Notes

At the modules level, the Elaborate pass:

- elaborates signatures with interfaces (see `interface.sig` and `interface.fun`)

  The main trick is to use disjoint sets to efficiently handle sharing of tycons and of structures and then to copy signatures as dags rather than as trees.

- checks functors at the point of definition, using functor summaries to speed up checking of functor applications.

  When a functor is first type checked, we keep track of the dummy argument structure and the dummy result structure, as well as all the tycons that were created while elaborating the body. Then, if we later need to type check an application of the functor (as opposed to defunctorize an application), we pair up tycons in the dummy argument structure with the actual argument structure and then replace the dummy tycons with the actual tycons in the dummy result structure, yielding the actual result structure. We also generate new tycons for all the tycons that we created while originally elaborating the body.

- handles opaque signature constraints.

  This is implemented by building a dummy structure realized from the signature, just as we would for a functor argument when type checking a functor. The dummy structure contains exactly the type information that is in the signature, which is what opacity requires. We then replace the variables (and constructors) in the dummy structure with the corresponding variables (and constructors) from the actual structure so that the translation to CoreML uses the right stuff. For each tycon in the dummy structure, we keep track of the corresponding type structure in the actual structure. This is used when producing the CoreML types (see `expandOpaque` in `type-env.sig` and `type-env.fun`).

  Then, within each `structure` or `functor` body, for each declaration (`<dec>` in the Standard ML grammar), the Elaborate pass does three steps:

  1. ScopeInference
  2. – PrecedenceParse

    - _{ex,im}port expansion
    - profiling insertion
    - unification
3. Overloaded {constant, function, record pattern} resolution

Defunctorization

The Elaborate pass performs a number of duties historically assigned to the Defunctorize pass.

As part of the Elaborate pass, all module level constructs (open, signature, structure, functor, long identifiers) are removed. This works because the Elaborate pass assigns a unique name to every type and variable in the program. This also allows the Elaborate pass to eliminate local declarations, which are purely for namespace management.

Examples

Here are a number of examples of elaboration.

- All variables bound in val declarations are renamed.

```
val x = 13
val y = x
```

```
val x_0 = 13
val y_0 = x_0
```

- All variables in fun declarations are renamed.

```
fun f x = g x
and g y = f y
```

```
fun f_0 x_0 = g_0 x_0
and g_0 y_0 = f_0 y_0
```

- Type abbreviations are removed, and the abbreviation is expanded wherever it is used.

```
type 'a u = int * 'a
type 'b t = 'b u * real
fun f (x : bool t) = x
```

```
fun f_0 (x_0 : (int * bool) * real) = x_0
```

- Exception declarations create a new constructor and rename the type.

```
type t = int
exception E of t * real
```

```
exception E_0 of int * real
```

- The type and value constructors in datatype declarations are renamed.

```
datatype t = A of int | B of real * t
```

```
datatype t_0 = A_0 of int | B_0 of real * t_0
```

- Local declarations are moved to the top-level. The environment keeps track of the variables in scope.

```
val x = 13
local val x = 14
in val y = x
end
val z = x
```

```
val x_0 = 13
val x_1 = 14
val y_0 = x_1
val z_0 = x_0
```

- Structure declarations are eliminated, with all declarations moved to the top level. Long identifiers are renamed.

```
structure S =
   struct
      type t = int
      val x : t = 13
   end
val y : S.t = S.x
```

```
val x_0 : int = 13
val y_0 : int = x_0
```

- Open declarations are eliminated.

```
val x = 13
val y = 14
structure S =
   struct
     val x = 15
   end
open S
val z = x + y
```

```
val x_0 = 13
val y_0 = 14
val x_1 = 15
val z_0 = x_1 + y_0
```

- Functor declarations are eliminated, and the body of a functor is duplicated wherever the functor is applied.

```
functor F(val x : int) =
   struct
     val y = x
   end
structure F1 = F(val x = 13)
structure F2 = F(val x = 14)
val z = F1.y + F2.y
```

```
val x_0 = 13
val y_0 = x_0
val x_1 = 14
val y_1 = x_1
val z_0 = y_0 + y_1
```

- Signature constraints are eliminated. Note that signatures do affect how subsequent variables are renamed.

```
val y = 13
structure S : sig
                 val x : int
              end =
   struct
      val x = 14
      val y = x
   end
open S
val z = x + y
```

```
val y_0 = 13
val x_0 = 14
val y_1 = x_0
val z_0 = x_0 + y_0
```

Emacs

SML modes

There are a few Emacs modes for SML.

- `sml-mode`
  - http://www.xemacs.org/Documentation/packages/html/sml-mode_3.html
  - http://www.smlnj.org/doc/Emacs/sml-mode.html
  - http://www.iro.umontreal.ca/%7Emonnier/elisp/
- `mlton.el` contains the Emacs lisp that StephenWeeks uses to interact with MLton (in addition to using `sml-mode`).
- http://primate.net/%7Eitz/mindent.tar, developed by Ian Zimmerman, who writes:

> Unlike the widespread `sml-mode.el` it doesn't try to indent code based on ML syntax. I gradually got skeptical about this approach after writing the initial indentation support for caml mode and watching it bloat insanely as the language added new features. Also, any such attempts that I know of impose a particular coding style, or at best a choice among a limited set of styles, which I now oppose. Instead my mode is based on a generic package which provides manual bindable commands for common indentation operations (example: indent the current line under the n-th occurrence of a particular character in the previous non-blank line).

MLB modes

There is a mode for editing ML Basis files.

- `esml-mlb-mode.el` (plus other files)

Definitions and uses

There is a mode that supports the precise def-use information that MLton can output. It highlights definitions and uses and provides commands for navigation (e.g., `jump-to-def`, `jump-to-next`, `list-all-refs`). It can be handy, for example, for navigating in the MLton compiler source code. See EmacsDefUseMode for further information.

Building on the background

Tired of manually starting/stopping/restarting builds after editing files? Now you don't have to. See EmacsBgBuildMode for further information.

Error messages

MLton's error messages are not among those that the Emacs `next-error` parser natively understands. The easiest way to fix this is to add the following to your `.emacs` to teach Emacs to recognize MLton's error messages.

```
(require 'compile)
(add-to-list 'compilation-error-regexp-alist 'mlton)
(add-to-list 'compilation-error-regexp-alist-alist
             '(mlton
               "^[[:space:]]*\\(\\(?:\\(Error\\)\\|\\(Warning\\)\\|\\(\\(?:\\(?:defn\\|spec ↩
                  \\) at\\)\\|\\(?:escape \\(?:from\\|to\\)\\)\\|\\(?:scoped at\\)\\)\\): ↩
                  \\(.+\\) \\([0-9]+\\)\\.\\([0-9]+\\)\\(?:-\\([0-9]+\\)\\.\\([0-9]+\\)\\) ↩
                  ?\\.?\\)$"
               5 (6 . 8) (7 . 9) (3 . 4) 1))
```

EmacsBgBuildMode

Do you really want to think about starting a build of you project? What if you had a personal slave that would restart a build of your project whenever you save any file belonging to that project? The bg-build mode does just that. Just save the file, a compile is started (silently!), you can continue working without even thinking about starting a build, and if there are errors, you are notified (with a message), and can then jump to errors.

This mode is not specific to MLton per se, but is particularly useful for working with MLton due to the longer compile times. By the time you start wondering about possible errors, the build is already on the way.

Functionality and Features

- Each time a file is saved, and after a user configurable delay period has been exhausted, a build is started silently in the background.
- When the build is finished, a status indicator (message) is displayed non-intrusively.
- At any time, you can switch to a build process buffer where all the messages from the build are shown.
- Optionally highlights (error/warning) message locations in (source code) buffers after a finished build.
- After a build has finished, you can jump to locations of warnings and errors from the build process buffer or by using the `first-error` and `next-error` commands.
- When a build fails, bg-build mode can optionally execute a user specified command. By default, bg-build mode executes `first-error`.
- When starting a build of a particular project, a possible previous live build of the same project is interrupted first.
- A project configuration file specifies the commands required to build a project.
- Multiple projects can be loaded into bg-build mode and bg-build mode can build a given maximum number of projects concurrently.
- Supports both Gnu Emacs and XEmacs.

Download

There is no package for the mode at the moment. To install the mode you need to fetch the Emacs Lisp, `*.el`, files from the MLton repository: `emacs`.

Setup

The easiest way to load the mode is to first tell Emacs where to find the files. For example, add

```
(add-to-list 'load-path (file-truename "path-to-the-el-files"))
```

to your `~/.emacs` or `~/.xemacs/init.el`. You'll probably also want to start the mode automatically by adding

```
(require 'bg-build-mode)
(bg-build-mode)
```

to your Emacs init file. Once the mode is activated, you should see the `BGB` indicator on the mode line.

MLton and Compilation-Mode

At the time of writing, neither Gnu Emacs nor XEmacs contain an error regexp that would match MLton's messages.

If you use Gnu Emacs, insert the following code into your `.emacs` file:

```
(require 'compile)
(add-to-list
 'compilation-error-regexp-alist
 '("^\\(Warning\\|Error\\): \\(.+\\) \\([0-9]+\\)\\.\\([0-9]+\\)\\.$"
   2 3 4))
```

If you use XEmacs, insert the following code into your `init.el` file:

```
(require 'compile)
(add-to-list
 'compilation-error-regexp-alist-alist
 '(mlton
   ("^\\(Warning\\|Error\\): \\(.+\\) \\([0-9]+\\)\\.\\([0-9]+\\)\\.$"
    2 3 4)))
(compilation-build-compilation-error-regexp-alist)
```

Usage

Typically projects are built (or compiled) using a tool like `make`, but the details vary. The bg-build mode needs a project configuration file to know how to build your project. A project configuration file basically contains an Emacs Lisp expression calling a function named `bg-build` that returns a project object. A simple example of a project configuration file would be the (`Build.bgb`) file used with smlbot:

```
(bg-build
 :name  "SML-Bot"
 :shell "nice -n5 make all")
```

The `bg-build` function takes a number of keyword arguments:

- `:name` specifies the name of the project. This can be any expression that evaluates to a string or to a nullary function that returns a string.
- `:shell` specifies a shell command to execute. This can be any expression that evaluates to a string, a list of strings, or to a nullary function returning a list of strings.
- `:build?` specifies a predicate to determine whether the project should be built after some files have been modified. The predicate is given a list of filenames and should return a non-nil value when the project should be built and nil otherwise.

All of the keyword arguments, except `:shell`, are optional and can be left out.

Note the use of the `nice` command above. It means that background build process is given a lower priority by the system process scheduler. Assuming your machine has enough memory, using nice ensures that your computer remains responsive. (You probably won't even notice when a build is started.)

Once you have written a project file for bg-build mode. Use the `bg-build-add-project` command to load the project file for bg-build mode. The bg-build mode can also optionally load recent project files automatically at startup.

After the project file has been loaded and bg-build mode activated, each time you save a file in Emacs, the bg-build mode tries to build your project.

The `bg-build-status` command creates a buffer that displays some status information on builds and allows you to manage projects (start builds explicitly, remove a project from bg-build, . . .) as well as visit buffers created by bg-build. Notice the count of started builds. At the end of the day it can be in the hundreds or thousands. Imagine the number of times you've been relieved of starting a build explicitly!

EmacsDefUseMode

MLton provides an option, `-show-def-use file`, to output precise (giving exact source locations) and accurate (including all uses and no false data) whole-program def-use information to a file. Unlike typical tags facilities, the information includes local variables and distinguishes between different definitions even when they have the same name. The def-use Emacs mode uses the information to provide navigation support, which can be particularly useful while reading SML programs compiled with MLton (such as the MLton compiler itself).

Screen Capture

Note the highlighting and the type displayed in the minibuffer.

```
emacs@localhost.localdomain
File Edit Options Buffers Tools SML Help
               (* First a plain old type rep for our data: *)
               val t1 = iso (record (R' "id" int
                                   *` R' "name" string))
                            (fn {id = a, name = b} => a & b,
                             fn a & b => {id = a, name = b})

               (* Then we assign version {1} to the type: *)
               val t = versioned $ 1 t1

               val pickleV1 = pickle t

               (* Then a plain old type rep for our new data: *)
               val t2 = iso (record (R' "id" int
                                   *` R' "extra" bool
                                   *` R' "name" string))
                            (fn {id = a, extra = b, name = c} => a & b & c,
                             fn a & b & c => {id = a, extra = b, name = c})

               (* Then we assign version {2} to the new type, keeping the
                * version {1} for the old type: *)
               val t = versioned (version 1 t1
                                     (fn {id, name} =>
                                         {id = id, extra = false, name = name}))
                                 $ 2 t2

               (* Note that the original versioned {t} is no longer needed.
                * In an actual program, you would have just edited the
                * original definition instead of introducing a new one.
                * However, the old type rep is required if you wish to be
                * able to unpickle old versions. *)
            in
               thatEq t {expect = {id = 1, extra = false, name = "whatever"},
                         actual = unpickle t
                                     (pickleV1 {id = 1, name = "whatever"})}
             ; thatEq t {expect = {id = 3, extra = true, name = "whenever"},
                         actual = unpickle t (pickle t {id = 3, extra = true,
--:--  pickle.sml     28% (99,41)    SVN:6391  (SML BGB DU)----------------------------
   {id: int, name: string} -> string
```

Features

- Highlights definitions and uses. Different colors for definitions, unused definitions, and uses.
- Shows types (with highlighting) of variable definitions in the minibuffer.

- Navigation: `jump-to-def`, `jump-to-next`, and `jump-to-prev`. These work precisely (no searching involved).
- Can list, visit and mark all references to a definition (within a program).
- Automatically reloads updated def-use files.
- Automatically loads previously used def-use files at startup.
- Supports both Gnu Emacs and XEmacs.

Download

There is no separate package for the def-use mode although the mode has been relatively stable for some time already. To install the mode you need to get the Emacs Lisp, `*.el`, files from MLton's repository: `emacs`. The easiest way to get the files is to use Git to access MLton's sources.

Setup

The easiest way to load def-use mode is to first tell Emacs where to find the files. For example, add

```
(add-to-list 'load-path (file-truename "path-to-the-el-files"))
```

to your `~/.emacs` or `~/.xemacs/init.el`. You'll probably also want to start `def-use-mode` automatically by adding

```
(require 'esml-du-mlton)
(def-use-mode)
```

to your Emacs init file. Once the def-use mode is activated, you should see the `DU` indicator on the mode line.

Usage

To use def-use mode one typically first sets up the program's makefile or build script so that the def-use information is saved each time the program is compiled. In addition to the `-show-def-use` *`file`* option, the `-prefer-abs-paths true` expert option is required. Note that the time it takes to save the information is small (compared to type-checking), so it is recommended to simply add the options to the MLton invocation that compiles the program. However, it is only necessary to type check the program (or library), so one can specify the `-stop tc` option. For example, suppose you have a program defined by an MLB file named `my-prg.mlb`, you can save the def-use information to the file `my-prg.du` by invoking MLton as:

```
mlton -prefer-abs-paths true -show-def-use my-prg.du -stop tc my-prg.mlb
```

Finally, one needs to tell the mode where to find the def-use information. This is done with the `esml-du-mlton` command. For example, to load the `my-prg.du` file, one would type:

```
M-x esml-du-mlton my-prg.du
```

After doing all of the above, find an SML file covered by the previously saved and loaded def-use information, and place the cursor at some variable (definition or use, it doesn't matter). You should see the variable being highlighted. (Note that specifications in signatures do not define variables.)

You might also want to setup and use the Bg-Build mode to start builds automatically.

Types

`-show-def-use` output was extended to include types of variable definitions in revision `r6333`. To get good type names, the types must be in scope at the end of the program. If you are using the ML Basis system, this means that the root MLB-file for your application should not wrap the libraries used in the application inside `local ...in ...end`, because that would remove them from the scope before the end of the program.

Enscript

GNU Enscript converts ASCII files to PostScript, HTML, and other output languages, applying language sensitive highlighting (similar to Emacs's font lock mode). Here are a few *states* files for highlighting Standard ML.

- `sml_simple.st` — Provides highlighting of keywords, string and character constants, and (nested) comments.
- `sml_verbose.st` — Supersedes the above, adding highlighting of numeric constants. Due to the limited parsing available, numeric record labels are highlighted as numeric constants, in all contexts. Likewise, a binding precedence separated from `infix` or `infixr` by a newline is highlighted as a numeric constant and a numeric record label selector separated from `#` by a newline is highlighted as a numeric constant.
- `sml_fancy.st` — Supersedes the above, adding highlighting of type and constructor bindings, highlighting of explicit binding of type variables at `val` and `fun` declarations, and separate highlighting of core and modules level keywords. Due to the limited parsing available, it is assumed that the input is a syntactically correct, top-level declaration.
- `sml_gaudy.st` — Supersedes the above, adding highlighting of type annotations, in both expressions and signatures. Due to the limited parsing available, it is assumed that the input is a syntactically correct, top-level declaration.

Install and use

- Version 1.6.3 of GNU Enscript
  - Copy all files to `/usr/share/enscript/hl/` or `.enscript/` in your home directory.
  - Invoke `enscript` with `--highlight=sml_simple` (or `--highlight=sml_verbose` or `--highlight=sml_fancy` or `--highlight=sml_gaudy`).
- Version 1.6.1 of GNU Enscript
  - Append `sml_all.st` to `/usr/share/enscript/enscript.st`
  - Invoke `enscript` with `--pretty-print=sml_simple` (or `--pretty-print=sml_verbose` or `--pretty-print=sml_fancy` or `--pretty-print=sml_gaudy`).

Feedback

Comments and suggestions should be directed to MatthewFluet.

EqualityType

An equality type is a type to which PolymorphicEquality can be applied. The Definition and the Basis Library precisely spell out which types are equality types.

- bool, char, IntInf.int, Int<N>.int, string, and Word<N>.word are equality types.
- for any t, both t array and t ref are equality types.
- if t is an equality type, then t list, and t vector are equality types.
- if t1, ..., tn are equality types, then t1 * ...* tn and {l1:t1, ..., ln:tn} are equality types.
- if t1, ..., tn are equality types and t AdmitsEquality, then (t1, ..., tn) t is an equality type.

To check that a type t is an equality type, use the following idiom.

```
structure S: sig eqtype t end =
   struct
      type t = ...
   end
```

Notably, exn and real are not equality types. Neither is t1 -> t2, for any t1 and t2.

Equality on arrays and ref cells is by identity, not structure. For example, ref 13 =ref 13 is false. On the other hand, equality for lists, strings, and vectors is by structure, not identity. For example, the following equalities hold.

```
val _ = [1, 2, 3] = 1 :: [2, 3]
val _ = "foo" = concat ["f", "o", "o"]
val _ = Vector.fromList [1, 2, 3] = Vector.tabulate (3, fn i => i + 1)
```

EqualityTypeVariable

An equality type variable is a type variable that starts with two or more primes, as in `''a` or `''b`. The canonical use of equality type variables is in specifying the type of the PolymorphicEquality function, which is `''a * ''a -> bool`. Equality type variables ensure that polymorphic equality is only used on equality types, by requiring that at every use of a polymorphic value, equality type variables are instantiated by equality types.

For example, the following program is type correct because polymorphic equality is applied to variables of type `''a`.

```
fun f (x: ''a, y: ''a): bool = x = y
```

On the other hand, the following program is not type correct, because polymorphic equality is applied to variables of type `'a`, which is not an equality type.

```
fun f (x: 'a, y: 'a): bool = x = y
```

MLton reports the following error, indicating that polymorphic equality expects equality types, but didn't get them.

```
Error: z.sml 1.30-1.34.
  Function applied to incorrect argument.
    expects: [<equality>] * [<equality>]
    but got: ['a] * ['a]
    in: = (x, y)
```

As an example of using such a function that requires equality types, suppose that `f` has polymorphic type `''a -> unit`. Then, `f 13` is type correct because `int` is an equality type. On the other hand, `f 13.0` and `f (fn x => x)` are not type correct, because `real` and arrow types are not equality types. We can test these facts with the following short programs. First, we verify that such an `f` can be applied to integers.

```
functor Ok (val f: ''a -> unit): sig end =
   struct
      val () = f 13
      val () = f 14
   end
```

We can do better, and verify that such an `f` can be applied to any integer.

```
functor Ok (val f: ''a -> unit): sig end =
   struct
      fun g (x: int) = f x
   end
```

Even better, we don't need to introduce a dummy function name; we can use a type constraint.

```
functor Ok (val f: ''a -> unit): sig end =
   struct
      val _ = f: int -> unit
   end
```

Even better, we can use a signature constraint.

```
functor Ok (S: sig val f: ''a -> unit end):
   sig val f: int -> unit end = S
```

This functor concisely verifies that a function of polymorphic type `''a -> unit` can be safely used as a function of type `int -> unit`.

As above, we can verify that such an `f` can not be used at non-equality types.

```
functor Bad (S: sig val f: ''a -> unit end):
   sig val f: real -> unit end = S

functor Bad (S: sig val f: ''a -> unit end):
   sig val f: ('a -> 'a) -> unit end = S
```

MLton reports the following errors.

```
Error: z.sml 2.4-2.30.
  Variable in structure disagrees with signature (type): f.
    structure: val f: [<equality>] -> _
    defn at: z.sml 1.25-1.25
    signature: val f: [real] -> _
    spec at: z.sml 2.12-2.12
Error: z.sml 5.4-5.36.
  Variable in structure disagrees with signature (type): f.
    structure: val f: [<equality>] -> _
    defn at: z.sml 4.25-4.25
    signature: val f: [_ -> _] -> _
    spec at: z.sml 5.12-5.12
```

Equality type variables in type and datatype declarations

Equality type variables can be used in type and datatype declarations; however they play no special role. For example,

```
type 'a t = 'a * int
```

is completely identical to

```
type ''a t = ''a * int
```

In particular, such a definition does *not* require that `t` only be applied to equality types.

Similarly,

```
datatype 'a t = A | B of 'a
```

is completely identical to

```
datatype ''a t = A | B of ''a
```

EtaExpansion

Eta expansion is a simple syntactic change used to work around the ValueRestriction in Standard ML.

The eta expansion of an expression `e` is the expression `fn z => e z`, where `z` does not occur in `e`. This only makes sense if `e` denotes a function, i.e. is of arrow type. Eta expansion delays the evaluation of `e` until the function is applied, and will re-evaluate `e` each time the function is applied.

The name "eta expansion" comes from the eta-conversion rule of the lambda calculus. Expansion refers to the directionality of the equivalence being used, namely taking `e` to `fn z => e z` rather than `fn z => e z` to `e` (eta contraction).

eXene

eXene is a multi-threaded X Window System toolkit written in ConcurrentML.

There is a group at K-State working toward eXene 2.0.

FAQ

Feel free to ask questions and to update answers by editing this page. Since we try to make as much information as possible available on the web site and we like to avoid duplication, many of the answers are simply links to a web page that answers the question.

How do you pronounce MLton?

Pronounce

What SML software has been ported to MLton?

Libraries

What graphical libraries are available for MLton?

Libraries

How does MLton's performance compare to other SML compilers and to other languages?

MLton has excellent performance.

Does MLton treat monomorphic arrays and vectors specially?

MLton implements monomorphic arrays and vectors (e.g. `BoolArray`, `Word8Vector`) exactly as instantiations of their polymorphic counterpart (e.g. `bool array`, `Word8.word vector`). Thus, there is no need to use the monomorphic versions except when required to interface with the Basis Library or for portability with other SML implementations.

Why do I get a Segfault/Bus error in a program that uses `IntInf`/`LargeInt` to calculate numbers with several hundred thousand digits?

GnuMP

How can I decrease compile-time memory usage?

- Compile with `-verbose 3` to find out if the problem is due to an SSA optimization pass. If so, compile with `-disable-pass` *`pass`* to skip that pass.
- Compile with `@MLton hash-cons 0.5 --`, which will instruct the runtime to hash cons the heap every other GC.
- Compile with `-polyvariance false`, which is an undocumented option that causes less code duplication.

Also, please Contact us to let us know the problem to help us better understand MLton's limitations.

How portable is SML code across SML compilers?

StandardMLPortability

Features

MLton has the following features.

Portability

- Runs on a variety of platforms.
  - ARM:
    - Linux (Debian)
  - Alpha:
    - Linux (Debian)
  - AMD64:
    - Darwin (Mac OS X)
    - FreeBSD
    - Linux (Debian, Fedora, Ubuntu, . . .)
    - OpenBSD
    - Solaris (10 and above)
  - HPPA:
    - HPUX (11.11 and above)
    - Linux (Debian)
  - IA64:
    - HPUX (11.11 and above)
    - Linux (Debian)
  - PowerPC:
    - AIX (5.2 and above)
    - Darwin (Mac OS X)
    - Linux (Debian, Fedora, . . .)
  - PowerPC64:
    - AIX (5.2 and above)
  - S390
    - Linux (Debian)
  - Sparc
    - Linux (Debian)
    - Solaris (8 and above)
  - X86:
    - Cygwin/Windows
    - Darwin (Mac OS X)
    - FreeBSD
    - Linux (Debian, Fedora, Ubuntu, . . .)
    - MinGW/Windows
    - NetBSD
    - OpenBSD
    - Solaris (10 and above)

Robustness

- Supports the full SML 97 language as given in The Definition of Standard ML (Revised).

  If there is a program that is valid according to the Definition that is rejected by MLton, or a program that is invalid according to the Definition that is accepted by MLton, it is a bug. For a list of known bugs, see UnresolvedBugs.

- A complete implementation of the Basis Library.

  MLton's implementation matches latest Basis Library specification, and includes a complete implementation of all the required modules, as well as many of the optional modules.

- Generates standalone executables.

  No additional code or libraries are necessary in order to run an executable, except for the standard shared libraries. MLton can also generate statically linked executables.

- Compiles large programs.

  MLton is sufficiently efficient and robust that it can compile large programs, including itself (over 190K lines). The distributed version of MLton was compiled by MLton.

- Support for large amounts of memory (up to 4G on 32-bit systems; more on 64-bit systems).

- Support for large array lengths (up to 2^{31}-1 on 32-bit systems; up to 2^{63}-1 on 64-bit systems).

- Support for large files, using 64-bit file positions.

Performance

- Executables have excellent running times.

- Generates small executables.

  MLton takes advantage of whole-program compilation to perform very aggressive dead-code elimination, which often leads to smaller executables than with other SML compilers.

- Untagged and unboxed native integers, reals, and words.

  In MLton, integers and words are 8 bits, 16 bits, 32 bits, and 64 bits and arithmetic does not have any overhead due to tagging or boxing. Also, reals (32-bit and 64-bit) are stored unboxed, avoiding any overhead due to boxing.

- Unboxed native arrays.

  In MLton, an array (or vector) of integers, reals, or words uses the natural C-like representation. This is fast and supports easy exchange of data with C. Monomorphic arrays (and vectors) use the same C-like representations as their polymorphic counterparts.

- Multiple garbage collection strategies.

- Fast arbitrary precision arithmetic (`IntInf`) based on GnuMP.

  For `IntInf` intensive programs, MLton can be an order of magnitude or more faster than Poly/ML or SML/NJ.

Tools

- Source-level Profiling of both time and allocation.

- MLLex lexer generator

- MLYacc parser generator

- MLNLFFIGen foreign-function-interface generator

Extensions

- A simple and fast C ForeignFunctionInterface that supports calling from SML to C and from C to SML.
- The ML Basis system for programming in the very large, separate delivery of library sources, and more.
- A number of extension libraries that provide useful functionality that cannot be implemented with the Basis Library. See below for an overview and MLtonStructure for details.
  - continuations
    MLton supports continuations via `callcc` and `throw`.
  - finalization
    MLton supports finalizable values of arbitrary type.
  - interval timers
    MLton supports the functionality of the C `setitimer` function.
  - random numbers
    MLton has functions similar to the C `rand` and `srand` functions, as well as support for access to `/dev/random` and `/dev/urandom`.
  - resource limits
    MLton has functions similar to the C `getrlimit` and `setrlimit` functions.
  - resource usage
    MLton supports a subset of the functionality of the C `getrusage` function.
  - signal handlers
    MLton supports signal handlers written in SML. Signal handlers run in a separate MLton thread, and have access to the thread that was interrupted by the signal. Signal handlers can be used in conjunction with threads to implement preemptive multitasking.
  - size primitive
    MLton includes a primitive that returns the size (in bytes) of any object. This can be useful in understanding the space behavior of a program.
  - system logging
    MLton has a complete interface to the C `syslog` function.
  - threads
    MLton has support for its own threads, upon which either preemptive or non-preemptive multitasking can be implemented. MLton also has support for Concurrent ML (CML).
  - weak pointers
    MLton supports weak pointers, which allow the garbage collector to reclaim objects that it would otherwise be forced to keep. Weak pointers are also used to provide finalization.
  - world save and restore
    MLton has a facility for saving the entire state of a computation to a file and restarting it later. This facility can be used for staging and for checkpointing computations. It can even be used from within signal handlers, allowing interrupt driven checkpointing.

FirstClassPolymorphism

First-class polymorphism is the ability to treat polymorphic functions just like other values: pass them as arguments, store them in data structures, etc. Although Standard ML does have polymorphic functions, it does not support first-class polymorphism.

For example, the following declares and uses the polymorphic function `id`.

```
val id = fn x => x
val _ = id 13
val _ = id "foo"
```

If SML supported first-class polymorphism, we could write the following.

```
fun useId id = (id 13; id "foo")
```

However, this does not type check. MLton reports the following error.

```
Error: z.sml 1.24-1.31.
  Function applied to incorrect argument.
    expects: [int]
    but got: [string]
    in: id "foo"
```

The error message arises because MLton infers from `id 13` that `id` accepts an integer argument, but that `id "foo"` is passing a string.

Using explicit types sheds some light on the problem.

```
fun useId (id: 'a -> 'a) = (id 13; id "foo")
```

On this, MLton reports the following errors.

```
Error: z.sml 1.29-1.33.
  Function applied to incorrect argument.
    expects: ['a]
    but got: [int]
    in: id 13
Error: z.sml 1.36-1.43.
  Function applied to incorrect argument.
    expects: ['a]
    but got: [string]
    in: id "foo"
```

The errors arise because the argument `id` is *not* polymorphic; rather, it is monomorphic, with type `'a -> 'a`. It is perfectly valid to apply `id` to a value of type `'a`, as in the following

```
fun useId (id: 'a -> 'a, x: 'a) = id x  (* type correct *)
```

So, what is the difference between the type specification on `id` in the following two declarations?

```
val id: 'a -> 'a = fn x => x
fun useId (id: 'a -> 'a) = (id 13; id "foo")
```

While the type specifications on `id` look identical, they mean different things. The difference can be made clearer by explicitly scoping the type variables.

```
val 'a id: 'a -> 'a = fn x => x
fun 'a useId (id: 'a -> 'a) = (id 13; id "foo")  (* type error *)
```

In `val 'a id`, the type variable scoping means that for any `'a`, `id` has type `'a -> 'a`. Hence, `id` can be applied to arguments of type `int`, `real`, etc. Similarly, in `fun 'a useId`, the scoping means that `useId` is a polymorphic function that for any `'a` takes a function of type `'a -> 'a` and does something. Thus, `useId` could be applied to a function of type `int -> int`, `real -> real`, etc.

One could imagine an extension of SML that allowed scoping of type variables at places other than `fun` or `val` declarations, as in the following.

```
fun useId (id: ('a).'a -> 'a) = (id 13; id "foo")  (* not SML *)
```

Such an extension would need to be thought through very carefully, as it could cause significant complications with TypeInference, possible even undecidability.

Fixpoints

This page discusses a framework that makes it possible to compute fixpoints over arbitrary products of abstract types. The code is from an Extended Basis library (README).

First the signature of the framework (tie.sig):

```
(**
 * A framework for computing fixpoints.
 *
 * In a strict language you sometimes want to provide a fixpoint
 * combinator for an abstract type {t} to make it possible to write
 * recursive definitions.  Unfortunately, a single combinator {fix} of the
 * type {(t -> t) -> t} does not support mutual recursion.  To support
 * mutual recursion, you would need to provide a family of fixpoint
 * combinators having types of the form {(u -> u) -> u} where {u} is a
 * type of the form {t * ... * t}.  Unfortunately, even such a family of
 * fixpoint combinators does not support mutual recursion over different
 * abstract types.
 *)
signature TIE = sig
   include ETAEXP'
   type 'a t = 'a etaexp
   (** The type of fixpoint witnesses. *)

   val fix : 'a t -> 'a Fix.t
   (**
    * Produces a fixpoint combinator from the given witness.  For example,
    * one can make a mutually recursive definition of functions:
    *
    *> val isEven & isOdd =
    *>     let open Tie in fix (function *` function) end
    *>        (fn isEven & isOdd =>
    *>            (fn 0 => true
    *>              | 1 => false
    *>              | n => isOdd (n-1)) &
    *>            (fn 0 => false
    *>              | 1 => true
    *>              | n => isEven (n-1)))
    *)

   (** == Making New Witnesses == *)

   val pure : ('a * 'a UnOp.t) Thunk.t -> 'a t
   (**
    * {pure} is a more general version of {tier}.  It is mostly useful for
    * computing fixpoints in a non-imperative manner.
    *)

   val tier : ('a * 'a Effect.t) Thunk.t -> 'a t
   (**
    * {tier} is used to define fixpoint witnesses for new abstract types
    * by providing a thunk whose instantiation allocates a mutable proxy
    * and a procedure for updating it with the result.
    *)

   val id : 'a -> 'a t
   (** {id x} is equivalent to {pure (const (x, id))}. *)

   (** == Combining Existing Witnesses == *)

   val iso : 'b t -> ('a, 'b) Iso.t -> 'a t
```

```
   (**
    * Given an isomorphism between {'a} and {'b} and a witness for {'b},
    * produces a witness for {'a}.  This is useful when you have a new
    * type that is isomorphic to some old type for which you already have
    * a witness.
    *)

   val product : 'a t * ('a -> 'b t) -> ('a, 'b) Product.t t
   (**
    * Dependent product combinator.  Given a witness for {'a} and a
    * constructor from a {'a} to witness for {'b}, produces a witness for
    * the product {('a, 'b) Product.t}.  The constructor for {'b} should
    * not access the (proxy) value {'a} before it has been fixed.
    *)

   val *` : 'a t * 'b t -> ('a, 'b) Product.t t
   (** {a *` b} is equivalent to {product (a, const b)}. *)

   val tuple2 : 'a t * 'b t -> ('a * 'b) t
   (**
    * Given witnesses for {'a} and {'b} produces a witness for the product
    * {'a * 'b}.
    *)

   (** == Particular Witnesses == *)

   val function : ('a -> 'b) t
   (** Witness for functions. *)
end
```

`fix` is a type-indexed function. The type-index parameter to `fix` is called a "witness". To compute fixpoints over products, one uses the `*`` operator to combine witnesses. To provide a fixpoint combinator for an abstract type, one implements a witness providing a thunk whose instantiation allocates a fresh, mutable proxy and a procedure for updating the proxy with the solution. Naturally this means that not all possible ways of computing a fixpoint of a particular type are possible under the framework. The `pure` combinator is a generalization of `tier`. The `iso` combinator is provided for reusing existing witnesses.

Note that instead of using an infix operator, we could alternatively employ an interface using Fold. Also, witnesses are eta-expanded to work around the value restriction, while maintaining abstraction.

Here is the implementation (`tie.sml`):

```
structure Tie :> TIE = struct
   open Product
   infix &
   type 'a etaexp_dom = Unit.t
   type 'a etaexp_cod = ('a * 'a UnOp.t) Thunk.t
   type 'a etaexp = 'a etaexp_dom -> 'a etaexp_cod
   type 'a t = 'a etaexp
   fun fix aT f = let val (a, ta) = aT () () in ta (f a) end
   val pure = Thunk.mk
   fun iso bT (iso as (_, b2a)) () () = let
      val (b, fB) = bT () ()
   in
      (b2a b, Fn.map iso fB)
   end
   fun product (aT, a2bT) () () = let
      val (a, fA) = aT () ()
      val (b, fB) = a2bT a () ()
   in
      (a & b, Product.map (fA, fB))
   end
   (* The rest are not primitive operations. *)
```

```
   fun op *` (aT, bT) = product (aT, Fn.const bT)
   fun tuple2 ab = iso (op *` ab) Product.isoTuple2
   fun tier th = pure ((fn (a, ua) => (a, Fn.const a o ua)) o th)
   fun id x = pure (Fn.const (x, Fn.id))
   fun function ? =
       pure (fn () => let
                  val r = ref (Basic.raising Fix.Fix)
               in
                  (fn x => !r x, fn f => (r := f ; f))
               end) ?
end
```

Let's then take a look at a couple of additional examples.

Here is a naive implementation of lazy promises:

```
structure Promise :> sig
   type 'a t
   val lazy : 'a Thunk.t -> 'a t
   val force : 'a t -> 'a
   val Y : 'a t Tie.t
end = struct
   datatype 'a t' =
      EXN of exn
    | THUNK of 'a Thunk.t
    | VALUE of 'a
   type 'a t = 'a t' Ref.t
   fun lazy f = ref (THUNK f)
   fun force t =
      case !t
       of EXN e   => raise e
        | THUNK f => (t := VALUE (f ()) handle e => t := EXN e ; force t)
        | VALUE v => v
   fun Y ? = Tie.tier (fn () => let
                             val r = lazy (raising Fix.Fix)
                          in
                             (r, r <\ op := o !)
                          end) ?
end
```

An example use of our naive lazy promises is to implement equally naive lazy streams:

```
structure Stream :> sig
   type 'a t
   val cons : 'a * 'a t -> 'a t
   val get : 'a t -> ('a * 'a t) Option.t
   val Y : 'a t Tie.t
end = struct
   datatype 'a t = IN of ('a * 'a t) Option.t Promise.t
   fun cons (x, xs) = IN (Promise.lazy (fn () => SOME (x, xs)))
   fun get (IN p) = Promise.force p
   fun Y ? = Tie.iso Promise.Y (fn IN p => p, IN) ?
end
```

Note that above we make use of the `iso` combinator. Here is a finite representation of an infinite stream of ones:

```
val ones = let
   open Tie Stream
in
   fix Y (fn ones => cons (1, ones))
end
```

Flatten

Flatten is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

This pass flattens arguments to SSA constructors, blocks, and functions.

If a tuple is explicitly available at all uses of a function (resp. block), then:

- The formals and call sites are changed so that the components of the tuple are passed.
- The tuple is reconstructed at the beginning of the body of the function (resp. block).

Similarly, if a tuple is explicitly available at all uses of a constructor, then:

- The constructor argument datatype is changed to flatten the tuple type.
- The tuple is passed flat at each `ConApp`.
- The tuple is reconstructed at each `Case` transfer target.

Implementation

- `flatten.fun`

Details and Notes

Fold

This page describes a technique that enables convenient syntax for a number of language features that are not explicitly supported by Standard ML, including: variable number of arguments, optional arguments and labeled arguments, array and vector literals, functional record update, and (seemingly) dependently typed functions like printf and scanf.

The key idea to *fold* is to define functions `fold`, `step0`, and `$` such that the following equation holds.

```
fold (a, f) (step0 h1) (step0 h2) ... (step0 hn) $
= f (hn (... (h2 (h1 a))))
```

The name `fold` comes because this is like a traditional list fold, where `a` is the *base element*, and each *step function*, `step0 hi`, corresponds to one element of the list and does one step of the fold. The name `$` is chosen to mean "end of arguments" from its common use in regular-expression syntax.

Unlike the usual list fold in which the same function is used to step over each element in the list, this fold allows the step functions to be different from each other, and even to be of different types. Also unlike the usual list fold, this fold includes a "finishing function", `f`, that is applied to the result of the fold. The presence of the finishing function may seem odd because there is no analogy in list fold. However, the finishing function is essential; without it, there would be no way for the folder to perform an arbitrary computation after processing all the arguments. The examples below will make this clear.

The functions `fold`, `step0`, and `$` are easy to define.

```
fun $ (a, f) = f a
fun id x = x
structure Fold =
   struct
      fun fold (a, f) g = g (a, f)
      fun step0 h (a, f) = fold (h a, f)
   end
```

We've placed `fold` and `step0` in the `Fold` structure but left `$` at the toplevel because it is convenient in code to always have `$` in scope. We've also defined the identity function, `id`, at the toplevel since we use it so frequently.

Plugging in the definitions, it is easy to verify the equation from above.

```
fold (a, f) (step0 h1) (step0 h2) ... (step0 hn) $
= step0 h1 (a, f) (step0 h2) ... (step0 hn) $
= fold (h1 a, f) (step0 h2) ... (step0 hn) $
= step0 h2 (h1 a, f) ... (step0 hn) $
= fold (h2 (h1 a), f) ... (step0 hn) $
...
= fold (hn (... (h2 (h1 a))), f) $
= $ (hn (... (h2 (h1 a))), f)
= f (hn (... (h2 (h1 a))))
```

Example: variable number of arguments

The simplest example of fold is accepting a variable number of (curried) arguments. We'll define a function `f` and argument `a` such that all of the following expressions are valid.

```
f $
f a $
f a a $
f a a a $
f a a a ... a a a $ (* as many a's as we want *)
```

Off-hand it may appear impossible that all of the above expressions are type correct SML — how can a function `f` accept a variable number of curried arguments? What could the type of `f` be? We'll have more to say later on how type checking works.

For now, once we have supplied the definitions below, you can check that the expressions are type correct by feeding them to your favorite SML implementation.

It is simple to define `f` and `a`. We define `f` as a folder whose base element is `()` and whose finish function does nothing. We define `a` as the step function that does nothing. The only trickiness is that we must eta expand the definition of `f` and `a` to work around the ValueRestriction; we frequently use eta expansion for this purpose without mention.

```
val base = ()
fun finish () = ()
fun step () = ()
val f = fn z => Fold.fold (base, finish) z
val a = fn z => Fold.step0 step z
```

One can easily apply the fold equation to verify by hand that `f` applied to any number of `a`'s evaluates to `()`.

```
f a ... a $
= finish (step (... (step base)))
= finish (step (... ()))
...
= finish ()
= ()
```

Example: variable-argument sum

Let's look at an example that computes something: a variable-argument function `sum` and a stepper `a` such that

```
sum (a i1) (a i2) ... (a im) $ = i1 + i2 + ... + im
```

The idea is simple — the folder starts with a base accumulator of `0` and the stepper adds each element to the accumulator, `s`, which the folder simply returns at the end.

```
val sum = fn z => Fold.fold (0, fn s => s) z
fun a i = Fold.step0 (fn s => i + s)
```

Using the fold equation, one can verify the following.

```
sum (a 1) (a 2) (a 3) $ = 6
```

Step1

It is sometimes syntactically convenient to omit the parentheses around the steps in a fold. This is easily done by defining a new function, `step1`, as follows.

```
structure Fold =
   struct
      open Fold
      fun step1 h (a, f) b = fold (h (b, a), f)
   end
```

From the definition of `step1`, we have the following equivalence.

```
fold (a, f) (step1 h) b
= step1 h (a, f) b
= fold (h (b, a), f)
```

Using the above equivalence, we can compute the following equation for `step1`.

```
fold (a, f) (step1 h1) b1 (step1 h2) b2 ... (step1 hn) bn $
= fold (h1 (b1, a), f) (step1 h2) b2 ... (step1 hn) bn $
= fold (h2 (b2, h1 (b1, a)), f) ... (step1 hn) bn $
= fold (hn (bn, ... (h2 (b2, h1 (b1, a)))), f) $
= f (hn (bn, ... (h2 (b2, h1 (b1, a)))))
```

Here is an example using `step1` to define a variable-argument product function, `prod`, with a convenient syntax.

```
val prod = fn z => Fold.fold (1, fn p => p) z
val ` = fn z => Fold.step1 (fn (i, p) => i * p) z
```

The functions `prod` and ``` ` ``` satisfy the following equation.

```
prod `i1 `i2 ... `im $ = i1 * i2 * ... * im
```

Note that in SML, ``` `i1 ``` is two different tokens, ``` ` ``` and `i1`. We often use ``` ` ``` for an instance of a `step1` function because of its syntactic unobtrusiveness and because no space is required to separate it from an alphanumeric token.

Also note that there are no parenthesis around the steps. That is, the following expression is not the same as the above one (in fact, it is not type correct).

```
prod (`i1) (`i2) ... (`im) $
```

Example: list literals

SML already has a syntax for list literals, e.g. `[w, x, y, z]`. However, using fold, we can define our own syntax.

```
val list = fn z => Fold.fold ([], rev) z
val ` = fn z => Fold.step1 (op ::) z
```

The idea is that the folder starts out with the empty list, the steps accumulate the elements into a list, and then the finishing function reverses the list at the end.

With these definitions one can write a list like:

```
list `w `x `y `z $
```

While the example is not practically useful, it does demonstrate the need for the finishing function to be incorporated in `fold`. Without a finishing function, every use of `list` would need to be wrapped in `rev`, as follows.

```
rev (list `w `x `y `z $)
```

The finishing function allows us to incorporate the reversal into the definition of `list`, and to treat `list` as a truly variable argument function, performing an arbitrary computation after receiving all of its arguments.

See ArrayLiteral for a similar use of `fold` that provides a syntax for array and vector literals, which are not built in to SML.

Fold right

Just as `fold` is analogous to a fold left, in which the functions are applied to the accumulator left-to-right, we can define a variant of `fold` that is analogous to a fold right, in which the functions are applied to the accumulator right-to-left. That is, we can define functions `foldr` and `step0` such that the following equation holds.

```
foldr (a, f) (step0 h1) (step0 h2) ... (step0 hn) $
= f (h1 (h2 (... (hn a))))
```

The implementation of fold right is easy, using fold. The idea is for the fold to start with `f` and for each step to precompose the next `hi`. Then, the finisher applies the composed function to the base value, `a`. Here is the code.

```
structure Foldr =
   struct
      fun foldr (a, f) = Fold.fold (f, fn g => g a)
      fun step0 h = Fold.step0 (fn g => g o h)
   end
```

Verifying the fold-right equation is straightforward, using the fold-left equation.

```
foldr (a, f) (Foldr.step0 h1) (Foldr.step0 h2) ... (Foldr.step0 hn) $
= fold (f, fn g => g a)
    (Fold.step0 (fn g => g o h1))
    (Fold.step0 (fn g => g o h2))
    ...
    (Fold.step0 (fn g => g o hn)) $
= (fn g => g a)
  ((fn g => g o hn) (... ((fn g => g o h2) ((fn g => g o h1) f))))
= (fn g => g a)
  ((fn g => g o hn) (... ((fn g => g o h2) (f o h1))))
= (fn g => g a) ((fn g => g o hn) (... (f o h1 o h2)))
= (fn g => g a) (f o h1 o h2 o ... o hn)
= (f o h1 o h2 o ... o hn) a
= f (h1 (h2 (... (hn a))))
```

One can also define the fold-right analogue of `step1`.

```
structure Foldr =
   struct
      open Foldr
      fun step1 h = Fold.step1 (fn (b, g) => g o (fn a => h (b, a)))
   end
```

Example: list literals via fold right

Revisiting the list literal example from earlier, we can use fold right to define a syntax for list literals that doesn't do a reversal.

```
val list = fn z => Foldr.foldr ([], fn l => l) z
val ` = fn z => Foldr.step1 (op ::) z
```

As before, with these definitions, one can write a list like:

```
list `w `x `y `z $
```

The difference between the fold-left and fold-right approaches is that the fold-right approach does not have to reverse the list at the end, since it accumulates the elements in the correct order. In practice, MLton will simplify away all of the intermediate function composition, so the the fold-right approach will be more efficient.

Mixing steppers

All of the examples so far have used the same step function throughout a fold. This need not be the case. For example, consider the following.

```
val n = fn z => Fold.fold (0, fn i => i) z
val I = fn z => Fold.step0 (fn i => i * 2) z
val O = fn z => Fold.step0 (fn i => i * 2 + 1) z
```

Here we have one folder, `n`, that can be used with two different steppers, `I` and `O`. By using the fold equation, one can verify the following equations.

```
n O $ = 0
n I $ = 1
n I O $ = 2
n I O I $ = 5
n I I I O $ = 14
```

That is, we've defined a syntax for writing binary integer constants.

Not only can one use different instances of `step0` in the same fold, one can also intermix uses of `step0` and `step1`. For example, consider the following.

```
val n = fn z => Fold.fold (0, fn i => i) z
val O = fn z => Fold.step0 (fn i => n * 8) z
val ` = fn z => Fold.step1 (fn (i, n) => n * 8 + i) z
```

Using the straightforward generalization of the fold equation to mixed steppers, one can verify the following equations.

```
n 0 $ = 0
n `3 O $ = 24
n `1 O `7 $ = 71
```

That is, we've defined a syntax for writing octal integer constants, with a special syntax, `O`, for the zero digit (admittedly contrived, since one could just write `` `0`` instead of `O`).

See NumericLiteral for a practical extension of this approach that supports numeric constants in any base and of any type.

(Seemingly) dependent types

A normal list fold always returns the same type no matter what elements are in the list or how long the list is. Variable-argument fold is more powerful, because the result type can vary based both on the arguments that are passed and on their number. This can provide the illusion of dependent types.

For example, consider the following.

```
val f = fn z => Fold.fold ((), id) z
val a = fn z => Fold.step0 (fn () => "hello") z
val b = fn z => Fold.step0 (fn () => 13) z
val c = fn z => Fold.step0 (fn () => (1, 2)) z
```

Using the fold equation, one can verify the following equations.

```
f a $ = "hello": string
f b $ = 13: int
f c $ = (1, 2): int * int
```

That is, `f` returns a value of a different type depending on whether it is applied to argument `a`, argument `b`, or argument `c`.

The following example shows how the type of a fold can depend on the number of arguments.

```
val grow = fn z => Fold.fold ([], fn l => l) z
val a = fn z => Fold.step0 (fn x => [x]) z
```

Using the fold equation, one can verify the following equations.

```
grow $ = []: 'a list
grow a $ = [[]]: 'a list list
grow a a $ = [[[]]]: 'a list list list
```

Clearly, the result type of a call to the variable argument `grow` function depends on the number of arguments that are passed.

As a reminder, this is well-typed SML. You can check it out in any implementation.

(Seemingly) dependently-typed functional results

Fold is especially useful when it returns a curried function whose arity depends on the number of arguments. For example, consider the following.

```
val makeSum = fn z => Fold.fold (id, fn f => f 0) z
val I = fn z => Fold.step0 (fn f => fn i => fn x => f (x + i)) z
```

The `makeSum` folder constructs a function whose arity depends on the number of `I` arguments and that adds together all of its arguments. For example, `makeSum I $` is of type `int -> int` and `makeSum I I $` is of type `int -> int -> int`.

One can use the fold equation to verify that the `makeSum` works correctly. For example, one can easily check by hand the following equations.

```
makeSum I $ 1 = 1
makeSum I I $ 1 2 = 3
makeSum I I I $ 1 2 3 = 6
```

Returning a function becomes especially interesting when there are steppers of different types. For example, the following `makeSum` folder constructs functions that sum integers and reals.

```
val makeSum = fn z => Foldr.foldr (id, fn f => f 0.0) z
val I = fn z => Foldr.step0 (fn f => fn x => fn i => f (x + real i)) z
val R = fn z => Foldr.step0 (fn f => fn x: real => fn r => f (x + r)) z
```

With these definitions, `makeSum I R $` is of type `int -> real -> real` and `makeSum R I I $` is of type `real -> int -> int -> real`. One can use the foldr equation to check the following equations.

```
makeSum I $ 1 = 1.0
makeSum I R $ 1 2.5 = 3.5
makeSum R I I $ 1.5 2 3 = 6.5
```

We used `foldr` instead of `fold` for this so that the order in which the specifiers `I` and `R` appear is the same as the order in which the arguments appear. Had we used `fold`, things would have been reversed.

An extension of this idea is sufficient to define Printf-like functions in SML.

An idiom for combining steps

It is sometimes useful to combine a number of steps together and name them as a single step. As a simple example, suppose that one often sees an integer follower by a real in the `makeSum` example above. One can define a new *compound step* `IR` as follows.

```
val IR = fn u => Fold.fold u I R
```

With this definition in place, one can verify the following.

```
makeSum IR IR $ 1 2.2 3 4.4 = 10.6
```

In general, one can combine steps `s1`, `s2`, `... sn` as

```
fn u => Fold.fold u s1 s2 ... sn
```

The following calculation shows why a compound step behaves as the composition of its constituent steps.

```
fold u (fn u => fold u s1 s2 ... sn)
= (fn u => fold u s1 s2 ... sn) u
= fold u s1 s2 ... sn
```

Post composition

Suppose we already have a function defined via fold, `w =fold (a, f)`, and we would like to construct a new fold function that is like `w`, but applies `g` to the result produced by `w`. This is similar to function composition, but we can't just do `g o w`, because we don't want to use `g` until `w` has been applied to all of its arguments and received the end-of-arguments terminator `$`.

More precisely, we want to define a post-composition function `post` that satisfies the following equation.

```
post (w, g) s1 ... sn $ = g (w s1 ... sn $)
```

Here is the definition of `post`.

```
structure Fold =
   struct
      open Fold
      fun post (w, g) s = w (fn (a, h) => s (a, g o h))
   end
```

The following calculations show that `post` satisfies the desired equation, where `w =fold (a, f)`.

```
post (w, g) s
= w (fn (a, h) => s (a, g o h))
= fold (a, f) (fn (a, h) => s (a, g o h))
= (fn (a, h) => s (a, g o h)) (a, f)
= s (a, g o f)
= fold (a, g o f) s
```

Now, suppose `si =step0 hi` for `i` from `1` to `n`.

```
post (w, g) s1 s2 ... sn $
= fold (a, g o f) s1 s2 ... sn $
= (g o f) (hn (... (h1 a)))
= g (f (hn (... (h1 a))))
= g (fold (a, f) s1 ... sn $)
= g (w s1 ... sn $)
```

For a practical example of post composition, see ArrayLiteral.

Lift

We now define a peculiar-looking function, `lift0`, that is, equationally speaking, equivalent to the identity function on a step function.

```
fun lift0 s (a, f) = fold (fold (a, id) s $, f)
```

Using the definitions, we can prove the following equation.

```
fold (a, f) (lift0 (step0 h)) = fold (a, f) (step0 h)
```

Here is the proof.

```
fold (a, f) (lift0 (step0 h))
= lift0 (step0 h) (a, f)
= fold (fold (a, id) (step0 h) $, f)
= fold (step0 h (a, id) $, f)
= fold (fold (h a, id) $, f)
= fold ($ (h a, id), f)
= fold (id (h a), f)
= fold (h a, f)
= step0 h (a, f)
= fold (a, f) (step0 h)
```

If `lift0` is the identity, then why even define it? The answer lies in the typing of fold expressions, which we have, until now, left unexplained.

Typing

Perhaps the most surprising aspect of fold is that it can be checked by the SML type system. The types involved in fold expressions are complex; fortunately type inference is able to deduce them. Nevertheless, it is instructive to study the types of fold functions and steppers. More importantly, it is essential to understand the typing aspects of fold in order to write down signatures of functions defined using fold and step.

Here is the `FOLD` signature, and a recapitulation of the entire `Fold` structure, with additional type annotations.

```
signature FOLD =
   sig
      type ('a, 'b, 'c, 'd) step = 'a * ('b -> 'c) -> 'd
      type ('a, 'b, 'c, 'd) t = ('a, 'b, 'c, 'd) step -> 'd
      type ('a1, 'a2, 'b, 'c, 'd) step0 =
         ('a1, 'b, 'c, ('a2, 'b, 'c, 'd) t) step
      type ('a11, 'a12, 'a2, 'b, 'c, 'd) step1 =
         ('a12, 'b, 'c, 'a11 -> ('a2, 'b, 'c, 'd) t) step

      val fold: 'a * ('b -> 'c) -> ('a, 'b, 'c, 'd) t
      val lift0: ('a1, 'a2, 'a2, 'a2, 'a2) step0
                 -> ('a1, 'a2, 'b, 'c, 'd) step0
      val post: ('a, 'b, 'c1, 'd) t * ('c1 -> 'c2)
                -> ('a, 'b, 'c2, 'd) t
      val step0: ('a1 -> 'a2) -> ('a1, 'a2, 'b, 'c, 'd) step0
      val step1: ('a11 * 'a12 -> 'a2)
                 -> ('a11, 'a12, 'a2, 'b, 'c, 'd) step1
   end

structure Fold:> FOLD =
   struct
      type ('a, 'b, 'c, 'd) step = 'a * ('b -> 'c) -> 'd

      type ('a, 'b, 'c, 'd) t = ('a, 'b, 'c, 'd) step -> 'd

      type ('a1, 'a2, 'b, 'c, 'd) step0 =
         ('a1, 'b, 'c, ('a2, 'b, 'c, 'd) t) step

      type ('a11, 'a12, 'a2, 'b, 'c, 'd) step1 =
         ('a12, 'b, 'c, 'a11 -> ('a2, 'b, 'c, 'd) t) step

      fun fold (a: 'a, f: 'b -> 'c)
               (g: ('a, 'b, 'c, 'd) step): 'd =
         g (a, f)

      fun step0 (h: 'a1 -> 'a2)
                (a1: 'a1, f: 'b -> 'c): ('a2, 'b, 'c, 'd) t =
         fold (h a1, f)

      fun step1 (h: 'a11 * 'a12 -> 'a2)
                (a12: 'a12, f: 'b -> 'c)
                (a11: 'a11): ('a2, 'b, 'c, 'd) t =
         fold (h (a11, a12), f)

      fun lift0 (s: ('a1, 'a2, 'a2, 'a2, 'a2) step0)
                (a: 'a1, f: 'b -> 'c): ('a2, 'b, 'c, 'd) t =
         fold (fold (a, id) s $, f)

      fun post (w: ('a, 'b, 'c1, 'd) t,
                g: 'c1 -> 'c2)
               (s: ('a, 'b, 'c2, 'd) step): 'd =
         w (fn (a, h) => s (a, g o h))
   end
```

That's a lot to swallow, so let's walk through it one step at a time. First, we have the definition of type `Fold.step`.

```
type ('a, 'b, 'c, 'd) step = 'a * ('b -> 'c) -> 'd
```

As a fold proceeds over its arguments, it maintains two things: the accumulator, of type `'a`, and the finishing function, of type `'b -> 'c`. Each step in the fold is a function that takes those two pieces (i.e. `'a * ('b -> 'c)` and does something to them (i.e. produces `'d`). The result type of the step is completely left open to be filled in by type inference, as it is an arrow type that is capable of consuming the rest of the arguments to the fold.

A folder, of type `Fold.t`, is a function that consumes a single step.

```
type ('a, 'b, 'c, 'd) t = ('a, 'b, 'c, 'd) step -> 'd
```

Expanding out the type, we have:

```
type ('a, 'b, 'c, 'd) t = ('a * ('b -> 'c) -> 'd) -> 'd
```

This shows that the only thing a folder does is to hand its accumulator (`'a`) and finisher (`'b -> 'c`) to the next step (`'a * ('b -> 'c) -> 'd`). If SML had first-class polymorphism, we would write the fold type as follows.

```
type ('a, 'b, 'c) t = Forall 'd . ('a, 'b, 'c, 'd) step -> 'd
```

This type definition shows that a folder had nothing to do with the rest of the fold, it only deals with the next step.

We now can understand the type of `fold`, which takes the initial value of the accumulator and the finishing function, and constructs a folder, i.e. a function awaiting the next step.

```
val fold: 'a * ('b -> 'c) -> ('a, 'b, 'c, 'd) t
fun fold (a: 'a, f: 'b -> 'c)
         (g: ('a, 'b, 'c, 'd) step): 'd =
   g (a, f)
```

Continuing on, we have the type of step functions.

```
type ('a1, 'a2, 'b, 'c, 'd) step0 =
   ('a1, 'b, 'c, ('a2, 'b, 'c, 'd) t) step
```

Expanding out the type a bit gives:

```
type ('a1, 'a2, 'b, 'c, 'd) step0 =
   'a1 * ('b -> 'c) -> ('a2, 'b, 'c, 'd) t
```

So, a step function takes the accumulator (`'a1`) and finishing function (`'b -> 'c`), which will be passed to it by the previous folder, and transforms them to a new folder. This new folder has a new accumulator (`'a2`) and the same finishing function.

Again, imagining that SML had first-class polymorphism makes the type clearer.

```
type ('a1, 'a2) step0 =
   Forall ('b, 'c) . ('a1, 'b, 'c, ('a2, 'b, 'c) t) step
```

Thus, in essence, a `step0` function is a wrapper around a function of type `'a1 -> 'a2`, which is exactly what the definition of `step0` does.

```
val step0: ('a1 -> 'a2) -> ('a1, 'a2, 'b, 'c, 'd) step0
fun step0 (h: 'a1 -> 'a2)
          (a1: 'a1, f: 'b -> 'c): ('a2, 'b, 'c, 'd) t =
   fold (h a1, f)
```

It is not much beyond `step0` to understand `step1`.

```
type ('a11, 'a12, 'a2, 'b, 'c, 'd) step1 =
   ('a12, 'b, 'c, 'a11 -> ('a2, 'b, 'c, 'd) t) step
```

A `step1` function takes the accumulator (`'a12`) and finisher (`'b -> 'c`) passed to it by the previous folder and transforms them into a function that consumes the next argument (`'a11`) and produces a folder that will continue the fold with a new accumulator (`'a2`) and the same finisher.

```
fun step1 (h: 'a11 * 'a12 -> 'a2)
          (a12: 'a12, f: 'b -> 'c)
          (a11: 'a11): ('a2, 'b, 'c, 'd) t =
   fold (h (a11, a12), f)
```

With first-class polymorphism, a `step1` function is more clearly seen as a wrapper around a binary function of type `'a11 * 'a12 -> 'a2`.

```
type ('a11, 'a12, 'a2) step1 =
   Forall ('b, 'c) . ('a12, 'b, 'c, 'a11 -> ('a2, 'b, 'c) t) step
```

The type of `post` is clear: it takes a folder with a finishing function that produces type `'c1`, and a function of type `'c1 -> 'c2` to postcompose onto the folder. It returns a new folder with a finishing function that produces type `'c2`.

```
val post: ('a, 'b, 'c1, 'd) t * ('c1 -> 'c2)
          -> ('a, 'b, 'c2, 'd) t
fun post (w: ('a, 'b, 'c1, 'd) t,
          g: 'c1 -> 'c2)
         (s: ('a, 'b, 'c2, 'd) step): 'd =
   w (fn (a, h) => s (a, g o h))
```

We will return to `lift0` after an example.

An example typing

Let's type check our simplest example, a variable-argument fold. Recall that we have a folder `f` and a stepper `a` defined as follows.

```
val f = fn z => Fold.fold ((), fn () => ()) z
val a = fn z => Fold.step0 (fn () => ()) z
```

Since the accumulator and finisher are uninteresting, we'll use some abbreviations to simplify things.

```
type 'd step = (unit, unit, unit, 'd) Fold.step
type 'd fold = 'd step -> 'd
```

With these abbreviations, `f` and `a` have the following polymorphic types.

```
f: 'd fold
a: 'd step
```

Suppose we want to type check

```
f a a a $: unit
```

As a reminder, the fully parenthesized expression is

```
((((f a) a) a) a) $
```

The observation that we will use repeatedly is that for any type `z`, if `f:z fold` and `s:z step`, then `f s:z`. So, if we want

```
(f a a a) $: unit
```

then we must have

```
f a a a: unit fold
$: unit step
```

Applying the observation again, we must have

```
f a a: unit fold fold
a: unit fold step
```

Applying the observation two more times leads to the following type derivation.

```
f: unit fold fold fold fold  a: unit fold fold fold step
f a: unit fold fold fold     a: unit fold fold step
f a a: unit fold fold        a: unit fold step
f a a a: unit fold           $: unit step
f a a a $: unit
```

So, each application is a fold that consumes the next step, producing a fold of one smaller type.

One can expand some of the type definitions in `f` to see that it is indeed a function that takes four curried arguments, each one a step function.

```
f: unit fold fold fold step
   -> unit fold fold step
   -> unit fold step
   -> unit step
   -> unit
```

This example shows why we must eta expand uses of `fold` and `step0` to work around the value restriction and make folders and steppers polymorphic. The type of a fold function like `f` depends on the number of arguments, and so will vary from use to use. Similarly, each occurrence of an argument like `a` has a different type, depending on the number of remaining arguments.

This example also shows that the type of a folder, when fully expanded, is exponential in the number of arguments: there are as many nested occurrences of the `fold` type constructor as there are arguments, and each occurrence duplicates its type argument. One can observe this exponential behavior in a type checker that doesn't share enough of the representation of types (e.g. one that represents types as trees rather than directed acyclic graphs).

Generalizing this type derivation to uses of fold where the accumulator and finisher are more interesting is straightforward. One simply includes the type of the accumulator, which may change, for each step, and the type of the finisher, which doesn't change from step to step.

Typing lift

The lack of first-class polymorphism in SML causes problems if one wants to use a step in a first-class way. Consider the following `double` function, which takes a step, `s`, and produces a composite step that does `s` twice.

```
fun double s = fn u => Fold.fold u s s
```

The definition of `double` is not type correct. The problem is that the type of a step depends on the number of remaining arguments but that the parameter `s` is not polymorphic, and so can not be used in two different positions.

Fortunately, we can define a function, `lift0`, that takes a monotyped step function and *lifts* it into a polymorphic step function. This is apparent in the type of `lift0`.

```
val lift0: ('a1, 'a2, 'a2, 'a2, 'a2) step0
           -> ('a1, 'a2, 'b, 'c, 'd) step0
fun lift0 (s: ('a1, 'a2, 'a2, 'a2, 'a2) step0)
          (a: 'a1, f: 'b -> 'c): ('a2, 'b, 'c, 'd) t =
   fold (fold (a, id) s $, f)
```

The following definition of `double` uses `lift0`, appropriately eta wrapped, to fix the problem.

```
fun double s =
   let
      val s = fn z => Fold.lift0 s z
   in
      fn u => Fold.fold u s s
   end
```

With that definition of `double` in place, we can use it as in the following example.

```
val f = fn z => Fold.fold ((), fn () => ()) z
val a = fn z => Fold.step0 (fn () => ()) z
val a2 = fn z => double a z
val () = f a a2 a a2 $
```

Of course, we must eta wrap the call `double` in order to use its result, which is a step function, polymorphically.

Hiding the type of the accumulator

For clarity and to avoid mistakes, it can be useful to hide the type of the accumulator in a fold. Reworking the simple variable-argument example to do this leads to the following.

```
structure S:>
  sig
     type ac
     val f: (ac, ac, unit, 'd) Fold.t
     val s: (ac, ac, 'b, 'c, 'd) Fold.step0
  end =
  struct
     type ac = unit
     val f = fn z => Fold.fold ((), fn () => ()) z
     val s = fn z => Fold.step0 (fn () => ()) z
  end
```

The idea is to name the accumulator type and use opaque signature matching to make it abstract. This can prevent improper manipulation of the accumulator by client code and ensure invariants that the folder and stepper would like to maintain.

For a practical example of this technique, see ArrayLiteral.

Also see

Fold has a number of practical applications. Here are some of them.

- ArrayLiteral
- Fold01N
- FunctionalRecordUpdate
- NumericLiteral
- OptionalArguments
- Printf
- VariableArityPolymorphism

There are a number of related techniques. Here are some of them.

- StaticSum
- TypeIndexedValues

Fold01N

A common use pattern of Fold is to define a variable-arity function that combines multiple arguments together using a binary function. It is slightly tricky to do this directly using fold, because of the special treatment required for the case of zero or one argument. Here is a structure, `Fold01N`, that solves the problem once and for all, and eases the definition of such functions.

```
structure Fold01N =
   struct
      fun fold {finish, start, zero} =
         Fold.fold ((id, finish, fn () => zero, start),
                    fn (finish, _, p, _) => finish (p ()))

      fun step0 {combine, input} =
         Fold.step0 (fn (_, finish, _, f) =>
                     (finish,
                      finish,
                      fn () => f input,
                      fn x' => combine (f input, x')))

      fun step1 {combine} z input =
         step0 {combine = combine, input = input} z
   end
```

If one has a value `zero`, and functions `start`, `c`, and `finish`, then one can define a variable-arity function `f` and stepper ` as follows.

```
val f = fn z => Fold01N.fold {finish = finish, start = start, zero = zero} z
val ` = fn z => Fold01N.step1 {combine = c} z
```

One can then use the fold equation to prove the following equations.

```
f $ = zero
f `a1 $ = finish (start a1)
f `a1 `a2 $ = finish (c (start a1, a2))
f `a1 `a2 `a3 $ = finish (c (c (start a1, a2), a3))
...
```

For an example of `Fold01N`, see VariableArityPolymorphism.

Typing Fold01N

Here is the signature for `Fold01N`. We use a trick to avoid having to duplicate the definition of some rather complex types in both the signature and the structure. We first define the types in a structure. Then, we define them via type re-definitions in the signature, and via `open` in the full structure.

```
structure Fold01N =
   struct
      type ('input, 'accum1, 'accum2, 'answer, 'zero,
            'a, 'b, 'c, 'd, 'e) t =
         (('zero -> 'zero)
          * ('accum2 -> 'answer)
          * (unit -> 'zero)
          * ('input -> 'accum1),
          ('a -> 'b) * 'c * (unit -> 'a) * 'd,
          'b,
          'e) Fold.t

       type ('input1, 'accum1, 'input2, 'accum2,
            'a, 'b, 'c, 'd, 'e, 'f) step0 =
         ('a * 'b * 'c * ('input1 -> 'accum1),
```

```
           'b * 'b * (unit -> 'accum1) * ('input2 -> 'accum2),
           'd, 'e, 'f) Fold.step0

      type ('accum1, 'input, 'accum2,
             'a, 'b, 'c, 'd, 'e, 'f, 'g) step1 =
          ('a,
           'b * 'c * 'd * ('a -> 'accum1),
           'c * 'c * (unit -> 'accum1) * ('input -> 'accum2),
           'e, 'f, 'g) Fold.step1
   end

signature FOLD_01N =
   sig
      type ('a, 'b, 'c, 'd, 'e, 'f, 'g, 'h, 'i, 'j) t =
         ('a, 'b, 'c, 'd, 'e, 'f, 'g, 'h, 'i, 'j) Fold01N.t
      type ('a, 'b, 'c, 'd, 'e, 'f, 'g, 'h, 'i, 'j) step0 =
         ('a, 'b, 'c, 'd, 'e, 'f, 'g, 'h, 'i, 'j) Fold01N.step0
      type ('a, 'b, 'c, 'd, 'e, 'f, 'g, 'h, 'i, 'j) step1 =
         ('a, 'b, 'c, 'd, 'e, 'f, 'g, 'h, 'i, 'j) Fold01N.step1

      val fold:
         {finish: 'accum2 -> 'answer,
          start: 'input -> 'accum1,
          zero: 'zero}
         -> ('input, 'accum1, 'accum2, 'answer, 'zero,
             'a, 'b, 'c, 'd, 'e) t

      val step0:
         {combine: 'accum1 * 'input2 -> 'accum2,
          input: 'input1}
         -> ('input1, 'accum1, 'input2, 'accum2,
             'a, 'b, 'c, 'd, 'e, 'f) step0

      val step1:
         {combine: 'accum1 * 'input -> 'accum2}
         -> ('accum1, 'input, 'accum2,
             'a, 'b, 'c, 'd, 'e, 'f, 'g) step1
   end

structure Fold01N: FOLD_01N =
   struct
      open Fold01N

      fun fold {finish, start, zero} =
         Fold.fold ((id, finish, fn () => zero, start),
                    fn (finish, _, p, _) => finish (p ()))

      fun step0 {combine, input} =
         Fold.step0 (fn (_, finish, _, f) =>
                      (finish,
                       finish,
                       fn () => f input,
                       fn x' => combine (f input, x')))

      fun step1 {combine} z input =
         step0 {combine = combine, input = input} z
   end
```

ForeignFunctionInterface

MLton's foreign function interface (FFI) extends Standard ML and makes it easy to take the address of C global objects, access C global variables, call from SML to C, and call from C to SML. MLton also provides ML-NLFFI, which is a higher-level FFI for calling C functions and manipulating C data from SML.

Overview

- Foreign Function Interface Types
- Foreign Function Interface Syntax

Importing Code into SML

- Calling From SML To C
- Calling From SML To C Function Pointer

Exporting Code from SML

- Calling From C To SML

Building System Libraries

- Library Support

ForeignFunctionInterfaceSyntax

MLton extends the syntax of SML with expressions that enable a ForeignFunctionInterface to C. The following description of the syntax uses some abbreviations.

C base type	*cBaseTy*	Foreign Function Interface types
C argument type	*cArgTy*	$cBaseTy_1$ `* ... *` $cBaseTy_n$ or `unit`
C return type	*cRetTy*	*cBaseTy* or `unit`
C function type	*cFuncTy*	*cArgTy* -> *cRetTy*
C pointer type	*cPtrTy*	`MLton.Pointer.t`

The type annotation and the semicolon are not optional in the syntax of ForeignFunctionInterface expressions. However, the type is lexed, parsed, and elaborated as an SML type, so any type (including type abbreviations) may be used, so long as it elaborates to a type of the correct form.

Address

```
_address "CFunctionOrVariableName" attr... : cPtrTy;
```

Denotes the address of the C function or variable.

`attr...` denotes a (possibly empty) sequence of attributes. The following attributes are recognized:

- `external` : import with external symbol scope (see LibrarySupport) (default).
- `private` : import with private symbol scope (see LibrarySupport).
- `public` : import with public symbol scope (see LibrarySupport).

See MLtonPointer for functions that manipulate C pointers.

Symbol

```
_symbol "CVariableName" attr... : (unit -> cBaseTy) * (cBaseTy -> unit);
```

Denotes the *getter* and *setter* for a C variable. The *cBaseTy*s must be identical.

`attr...` denotes a (possibly empty) sequence of attributes. The following attributes are recognized:

- `alloc` : allocate storage (and export a symbol) for the C variable.
- `external` : import or export with external symbol scope (see LibrarySupport) (default if not `alloc`).
- `private` : import or export with private symbol scope (see LibrarySupport).
- `public` : import or export with public symbol scope (see LibrarySupport) (default if `alloc`).

```
_symbol * : cPtrTy -> (unit -> cBaseTy) * (cBaseTy -> unit);
```

Denotes the *getter* and *setter* for a C pointer to a variable. The *cBaseTy*s must be identical.

Import

```
_import "CFunctionName" attr... : cFuncTy;
```

Denotes an SML function whose behavior is implemented by calling the C function. See Calling from SML to C for more details.

`attr...` denotes a (possibly empty) sequence of attributes. The following attributes are recognized:

- `cdecl` : call with the `cdecl` calling convention (default).
- `external` : import with external symbol scope (see LibrarySupport) (default).
- `impure`: assert that the function depends upon state and/or performs side effects (default).
- `private` : import with private symbol scope (see LibrarySupport).
- `public` : import with public symbol scope (see LibrarySupport).
- `pure`: assert that the function does not depend upon state or perform any side effects; such functions are subject to various optimizations (e.g., CommonSubexp, RemoveUnused)
- `reentrant`: assert that the function (directly or indirectly) calls an `_export`-ed SML function.
- `stdcall` : call with the `stdcall` calling convention (ignored except on Cygwin and MinGW).

```
_import * attr... : cPtrTy -> cFuncTy;
```

Denotes an SML function whose behavior is implemented by calling a C function through a C function pointer.

`attr...` denotes a (possibly empty) sequence of attributes. The following attributes are recognized:

- `cdecl` : call with the `cdecl` calling convention (default).
- `impure`: assert that the function depends upon state and/or performs side effects (default).
- `pure`: assert that the function does not depend upon state or perform any side effects; such functions are subject to various optimizations (e.g., CommonSubexp, RemoveUnused)
- `reentrant`: assert that the function (directly or indirectly) calls an `_export`-ed SML function.
- `stdcall` : call with the `stdcall` calling convention (ignored except on Cygwin and MinGW).

See Calling from SML to C function pointer for more details.

Export

```
_export "CFunctionName" attr... : cFuncTy -> unit;
```

Exports a C function with the name `CFunctionName` that can be used to call an SML function of the type *cFuncTy*. When the function denoted by the export expression is applied to an SML function `f`, subsequent C calls to `CFunctionName` will call `f`. It is an error to call `CFunctionName` before the export has been applied. The export may be applied more than once, with each application replacing any previous definition of `CFunctionName`.

`attr...` denotes a (possibly empty) sequence of attributes. The following attributes are recognized:

- `cdecl` : call with the `cdecl` calling convention (default).
- `private` : export with private symbol scope (see LibrarySupport).
- `public` : export with public symbol scope (see LibrarySupport) (default).
- `stdcall` : call with the `stdcall` calling convention (ignored except on Cygwin and MinGW).

See Calling from C to SML for more details.

ForeignFunctionInterfaceTypes

MLton's ForeignFunctionInterface only allows values of certain SML types to be passed between SML and C. The following types are allowed: `bool`, `char`, `int`, `real`, `word`. All of the different sizes of (fixed-sized) integers, reals, and words are supported as well: `Int8.int`, `Int16.int`, `Int32.int`, `Int64.int`, `Real32.real`, `Real64.real`, `Word8.word`, `Word16.word`, `Word32.word`, `Word64.word`. There is a special type, `MLton.Pointer.t`, for passing C pointers — see MLtonPointer for details.

Arrays, refs, and vectors of the above types are also allowed. Because in MLton monomorphic arrays and vectors are exactly the same as their polymorphic counterpart, these are also allowed. Hence, `string`, `char vector`, and `CharVector.vector` are also allowed. Strings are not null terminated, unless you manually do so from the SML side.

Unfortunately, passing tuples or datatypes is not allowed because that would interfere with representation optimizations.

The C header file that `-export-header` generates includes `typedefs` for the C types corresponding to the SML types. Here is the mapping between SML types and C types.

SML type	C typedef	C type	Note
`array`	`Pointer`	`unsigned char *`	
`bool`	`Bool`	`int32_t`	
`char`	`Char8`	`uint8_t`	
`Int8.int`	`Int8`	`int8_t`	
`Int16.int`	`Int16`	`int16_t`	
`Int32.int`	`Int32`	`int32_t`	
`Int64.int`	`Int64`	`int64_t`	
`int`	`Int32`	`int32_t`	(default)
`MLton.Pointer.t`	`Pointer`	`unsigned char *`	
`Real32.real`	`Real32`	`float`	
`Real64.real`	`Real64`	`double`	
`real`	`Real64`	`double`	(default)
`ref`	`Pointer`	`unsigned char *`	
`string`	`Pointer`	`unsigned char *`	(read only)
`vector`	`Pointer`	`unsigned char *`	(read only)
`Word8.word`	`Word8`	`uint8_t`	
`Word16.word`	`Word16`	`uint16_t`	
`Word32.word`	`Word32`	`uint32_t`	
`Word64.word`	`Word64`	`uint64_t`	
`word`	`Word32`	`uint32_t`	(default)

Note (default): The default `int`, `real`, and `word` types may be set by the `-default-type` *`type`* compiler option. The given C typedef and C types correspond to the default behavior.

Note (read only): Because MLton assumes that vectors and strings are read-only (and will perform optimizations that, for instance, cause them to share space), you must not modify the data pointed to by the `unsigned char *` in C code.

Although the C type of an array, ref, or vector is always `Pointer`, in reality, the object has the natural C representation. Your C code should cast to the appropriate C type if you want to keep the C compiler from complaining.

When calling an imported C function from SML that returns an array, ref, or vector result or when calling an exported SML function from C that takes an array, ref, or string argument, then the object must be an ML object allocated on the ML heap. (Although an array, ref, or vector object has the natural C representation, the object also has an additional header used by the SML runtime system.)

In addition, there is an MLBasis file, `$(SML_LIB)/basis/c-types.mlb`, which provides structure aliases for various C types:

C type	Structure	Signature
`char`	`C_Char`	`INTEGER`
`signed char`	`C_SChar`	`INTEGER`

unsigned char	C_UChar	WORD
short	C_Short	INTEGER
signed short	C_SShort	INTEGER
unsigned short	C_UShort	WORD
int	C_Int	INTEGER
signed int	C_SInt	INTEGER
unsigned int	C_UInt	WORD
long	C_Long	INTEGER
signed long	C_SLong	INTEGER
unsigned long	C_ULong	WORD
long long	C_LongLong	INTEGER
signed long long	C_SLongLong	INTEGER
unsigned long long	C_ULongLong	WORD
float	C_Float	REAL
double	C_Double	REAL
size_t	C_Size	WORD
ptrdiff_t	C_Ptrdiff	INTEGER
intmax_t	C_Intmax	INTEGER
uintmax_t	C_UIntmax	WORD
intptr_t	C_Intptr	INTEGER
uintptr_t	C_UIntptr	WORD
void *	C_Pointer	WORD

These aliases depend on the configuration of the C compiler for the target architecture, and are independent of the configuration of MLton (including the `-default-type` *`type`* compiler option).

ForLoops

A for-loop is typically used to iterate over a range of consecutive integers that denote indices of some sort. For example, in OCaml a for-loop takes either the form

```
for <name> = <lower> to <upper> do <body> done
```

or the form

```
for <name> = <upper> downto <lower> do <body> done
```

Some languages provide considerably more flexible for-loop or foreach-constructs.

A bit surprisingly, Standard ML provides special syntax for while-loops, but not for for-loops. Indeed, in SML, many uses of for-loops are better expressed using app, foldl/foldr, map and many other higher-order functions provided by the Basis Library for manipulating lists, vectors and arrays. However, the Basis Library does not provide a function for iterating over a range of integer values. Fortunately, it is very easy to write one.

A fairly simple design

The following implementation imitates both the syntax and semantics of the OCaml for-loop.

```
datatype for = to of int * int
             | downto of int * int

infix to downto

val for =
    fn lo to up =>
       (fn f => let fun loop lo = if lo > up then ()
                                  else (f lo; loop (lo+1))
                in loop lo end)
     | up downto lo =>
       (fn f => let fun loop up = if up < lo then ()
                                  else (f up; loop (up-1))
                in loop up end)
```

For example,

```
for (1 to 9)
    (fn i => print (Int.toString i))
```

would print 123456789 and

```
for (9 downto 1)
    (fn i => print (Int.toString i))
```

would print 987654321.

Straightforward formatting of nested loops

```
for (a to b)
    (fn i =>
        for (c to d)
            (fn j =>
                ...))
```

is fairly readable, but tends to cause the body of the loop to be indented quite deeply.

Off-by-one

The above design has an annoying feature. In practice, the upper bound of the iterated range is almost always excluded and most loops would subtract one from the upper bound:

```
for (0 to n-1) ...
for (n-1 downto 0) ...
```

It is probably better to break convention and exclude the upper bound by default, because it leads to more concise code and becomes idiomatic with very little practice. The iterator combinators described below exclude the upper bound by default.

Iterator combinators

While the simple `for`-function described in the previous section is probably good enough for many uses, it is a bit cumbersome when one needs to iterate over a Cartesian product. One might also want to iterate over more than just consecutive integers. It turns out that one can provide a library of iterator combinators that allow one to implement iterators more flexibly.

Since the types of the combinators may be a bit difficult to infer from their implementations, let's first take a look at a signature of the iterator combinator library:

```
signature ITER =
  sig
    type 'a t = ('a -> unit) -> unit

    val return : 'a -> 'a t
    val >>= : 'a t * ('a -> 'b t) -> 'b t

    val none : 'a t

    val to : int * int -> int t
    val downto : int * int -> int t

    val inList : 'a list -> 'a t
    val inVector : 'a vector -> 'a t
    val inArray : 'a array -> 'a t

    val using : ('a, 'b) StringCvt.reader -> 'b -> 'a t

    val when : 'a t * ('a -> bool) -> 'a t
    val by : 'a t * ('a -> 'b) -> 'b t
    val @@ : 'a t * 'a t -> 'a t
    val ** : 'a t * 'b t -> ('a, 'b) product t

    val for : 'a -> 'a
  end
```

Several of the above combinators are meant to be used as infix operators. Here is a set of suitable infix declarations:

```
infix 2 to downto
infix 1 @@ when by
infix 0 >>= **
```

A few notes are in order:

- The `'a t` type constructor with the `return` and `>>=` operators forms a monad.
- The `to` and `downto` combinators will omit the upper bound of the range.
- `for` is the identity function. It is purely for syntactic sugar and is not strictly required.
- The `@@` combinator produces an iterator for the concatenation of the given iterators.

- The `**` combinator produces an iterator for the Cartesian product of the given iterators.
  - See ProductType for the type constructor `('a, 'b) product` used in the type of the iterator produced by `**`.
- The `using` combinator allows one to iterate over slices, streams and many other kinds of sequences.
- `when` is the filtering combinator. The name `when` is inspired by OCaml's guard clauses.
- `by` is the mapping combinator.

The below implementation of the `ITER`-signature makes use of the following basic combinators:

```
fun const x _ = x
fun flip f x y = f y x
fun id x = x
fun opt fno fso = fn NONE => fno () | SOME ? => fso ?
fun pass x f = f x
```

Here is an implementation the `ITER`-signature:

```
structure Iter :> ITER =
  struct
    type 'a t = ('a -> unit) -> unit

    val return = pass
    fun (iA >>= a2iB) f = iA (flip a2iB f)

    val none = ignore

    fun (l to u) f = let fun `l = if l<u then (f l; `(l+1)) else () in `l end
    fun (u downto l) f = let fun `u = if u>l then (f (u-1); `(u-1)) else () in `u end

    fun inList ? = flip List.app ?
    fun inVector ? = flip Vector.app ?
    fun inArray ? = flip Array.app ?

    fun using get s f = let fun `s = opt (const ()) (fn (x, s) => (f x; `s)) (get s) in `s ↩
        end

    fun (iA when p) f = iA (fn a => if p a then f a else ())
    fun (iA by g) f = iA (f o g)
    fun (iA @@ iB) f = (iA f : unit; iB f)
    fun (iA ** iB) f = iA (fn a => iB (fn b => f (a & b)))

    val for = id
  end
```

Note that some of the above combinators (e.g. `**`) could be expressed in terms of the other combinators, most notably `return` and `>>=`. Another implementation issue worth mentioning is that `downto` is written specifically to avoid computing `l-1`, which could cause an `Overflow`.

To use the above combinators the `Iter`-structure needs to be opened

```
open Iter
```

and one usually also wants to declare the infix status of the operators as shown earlier.

Here is an example that illustrates some of the features:

```
for (0 to 10 when (fn x => x mod 3 <> 0) ** inList ["a", "b"] ** 2 downto 1 by real)
    (fn x & y & z =>
       print ("("^Int.toString x^", \""^y^"\", "^Real.toString z^")\n"))
```

Using the `Iter` combinators one can easily produce more complicated iterators. For example, here is an iterator over a "triangle":

```
fun triangle (l, u) = l to u >>= (fn i => i to u >>= (fn j => return (i, j)))
```

FrontEnd

FrontEnd is a translation pass from source to the AST IntermediateLanguage.

Description

This pass performs lexing and parsing to produce an abstract syntax tree.

Implementation

- `front-end.sig`
- `front-end.fun`

Details and Notes

The lexer is produced by MLLex from `ml.lex`.

The parser is produced by MLYacc from `ml.grm`.

The specifications for the lexer and parser were originally taken from SML/NJ (version 109.32), but have been heavily modified since then.

FSharp

F# is a functional programming language developed at Microsoft Research. F# was partly inspired by the OCaml language and shares some common core constructs with it. F# is integrated with Visual Studio 2010 as a first-class language.

FunctionalRecordUpdate

Functional record update is the copying of a record while replacing the values of some of the fields. Standard ML does not have explicit syntax for functional record update. We will show below how to implement functional record update in SML, with a little boilerplate code.

As an example, the functional update of the record

```
{a = 13, b = 14, c = 15}
```

with `c =16` yields a new record

```
{a = 13, b = 14, c = 16}
```

Functional record update also makes sense with multiple simultaneous updates. For example, the functional update of the record above with `a =18, c =19` yields a new record

```
{a = 18, b = 14, c = 19}
```

One could easily imagine an extension of the SML that supports functional record update. For example

```
e with {a = 16, b = 17}
```

would create a copy of the record denoted by `e` with field `a` replaced with `16` and `b` replaced with `17`.

Since there is no such syntax in SML, we now show how to implement functional record update directly. We first give a simple implementation that has a number of problems. We then give an advanced implementation, that, while complex underneath, is a reusable library that admits simple use.

Simple implementation

To support functional record update on the record type

```
{a: 'a, b: 'b, c: 'c}
```

first, define an update function for each component.

```
fun withA ({a = _, b, c}, a) = {a = a, b = b, c = c}
fun withB ({a, b = _, c}, b) = {a = a, b = b, c = c}
fun withC ({a, b, c = _}, c) = {a = a, b = b, c = c}
```

Then, one can express `e with {a =16, b =17}` as

```
withB (withA (e, 16), 17)
```

With infix notation

```
infix withA withB withC
```

the syntax is almost as concise as a language extension.

```
e withA 16 withB 17
```

This approach suffers from the fact that the amount of boilerplate code is quadratic in the number of record fields. Furthermore, changing, adding, or deleting a field requires time proportional to the number of fields (because each `with<L>` function must be changed). It is also annoying to have to define a `with<L>` function, possibly with a fixity declaration, for each field.

Fortunately, there is a solution to these problems.

Advanced implementation

Using Fold one can define a family of `makeUpdate<N>` functions and single *update* operator `U` so that one can define a functional record update function for any record type simply by specifying a (trivial) isomorphism between that type and function argument list. For example, suppose that we would like to do functional record update on records with fields `a` and `b`. Then one defines a function `updateAB` as follows.

```
val updateAB =
   fn z =>
   let
      fun from v1 v2 = {a = v1, b = v2}
      fun to f {a = v1, b = v2} = f v1 v2
   in
      makeUpdate2 (from, from, to)
   end
   z
```

The functions `from` (think *from function arguments*) and `to` (think *to function arguements*) specify an isomorphism between `a`,`b` records and function arguments. There is a second use of `from` to work around the lack of first-class polymorphism in SML.

With the definition of `updateAB` in place, the following expressions are valid.

```
updateAB {a = 13, b = "hello"} (set#b "goodbye") $
updateAB {a = 13.5, b = true} (set#b false) (set#a 12.5) $
```

As another example, suppose that we would like to do functional record update on records with fields `b`, `c`, and `d`. Then one defines a function `updateBCD` as follows.

```
val updateBCD =
   fn z =>
   let
      fun from v1 v2 v3 = {b = v1, c = v2, d = v3}
      fun to f {b = v1, c = v2, d = v3} = f v1 v2 v3
   in
      makeUpdate3 (from, from, to)
   end
   z
```

With the definition of `updateBCD` in place, the following expression is valid.

```
updateBCD {b = 1, c = 2, d = 3} (set#c 4) (set#c 5) $
```

Note that not all fields need be updated and that the same field may be updated multiple times. Further note that the same `set` operator is used for all update functions (in the above, for both `updateAB` and `updateBCD`).

In general, to define a functional-record-update function on records with fields `f1`, `f2`, ..., `fN`, use the following template.

```
val update =
   fn z =>
   let
      fun from v1 v2 ... vn = {f1 = v1, f2 = v2, ..., fn = vn}
      fun to f {f1 = v1, f2 = v2, ..., fn = vn} = v1 v2 ... vn
   in
      makeUpdateN (from, from, to)
   end
   z
```

With this, one can update a record as follows.

```
update {f1 = v1, ..., fn = vn} (set#fi1 vi1) ... (set#fim vim) $
```

The `FunctionalRecordUpdate` structure

Here is the implementation of functional record update.

```
structure FunctionalRecordUpdate =
   struct
      local
         fun next g (f, z) x = g (f x, z)
         fun f1 (f, z) x = f (z x)
         fun f2  z = next f1  z
         fun f3  z = next f2  z

         fun c0  from = from
         fun c1  from = c0  from f1
         fun c2  from = c1  from f2
         fun c3  from = c2  from f3

         fun makeUpdate cX (from, from', to) record =
            let
               fun ops () = cX from'
               fun vars f = to f record
            in
               Fold.fold ((vars, ops), fn (vars, _) => vars from)
            end
      in
         fun makeUpdate0  z = makeUpdate c0  z
         fun makeUpdate1  z = makeUpdate c1  z
         fun makeUpdate2  z = makeUpdate c2  z
         fun makeUpdate3  z = makeUpdate c3  z

         fun upd z = Fold.step2 (fn (s, f, (vars, ops)) => (fn out => vars (s (ops ()) (out ↩
             , f)), ops)) z
         fun set z = Fold.step2 (fn (s, v, (vars, ops)) => (fn out => vars (s (ops ()) (out ↩
             , fn _ => v)), ops)) z
      end
   end
```

The idea of `makeUpdate` is to build a record of functions which can replace the contents of one argument out of a list of arguments. The functions `f`<*X*> replace the 0th, 1st, ... argument with their argument `z`. The `c`<*X*> functions pass the first *X* `f` functions to the record constructor.

The `#field` notation of Standard ML allows us to select the map function which replaces the corresponding argument. By converting the record to an argument list, feeding that list through the selected map function and piping the list into the record constructor, functional record update is achieved.

Efficiency

With MLton, the efficiency of this approach is as good as one would expect with the special syntax. Namely a sequence of updates will be optimized into a single record construction that copies the unchanged fields and fills in the changed fields with their new values.

Before Sep 14, 2009, this page advocated an alternative implementation of FunctionalRecordUpdate. However, the old structure caused exponentially increasing compile times. We advise you to switch to the newer version.

Applications

Functional record update can be used to implement labelled optional arguments.

fxp

fxp is an XML parser written in Standard ML.

It has a patch to compile with MLton.

GarbageCollection

For a good introduction and overview to garbage collection, see Jones99.

MLton's garbage collector uses copying, mark-compact, and generational collection, automatically switching between them at run time based on the amount of live data relative to the amount of RAM. The runtime system tries to keep the heap within RAM if at all possible.

MLton's copying collector is a simple, two-space, breadth-first, Cheney-style collector. The design for the generational and mark-compact GC is based on Sansom91.

Design notes

- http://www.mlton.org/pipermail/mlton/2002-May/012420.html
  object layout and header word design

Also see

- Regions

GenerativeDatatype

In Standard ML, datatype declarations are said to be *generative*, because each time a datatype declaration is evaluated, it yields a new type. Thus, any attempt to mix the types will lead to a type error at compile-time. The following program, which does not type check, demonstrates this.

```
functor F () =
   struct
      datatype t = T
   end
structure S1 = F ()
structure S2 = F ()
val _: S1.t -> S2.t = fn x => x
```

Generativity also means that two different datatype declarations define different types, even if they define identical constructors. The following program does not type check due to this.

```
datatype t = A | B
val a1 = A
datatype t = A | B
val a2 = A
val _ = if true then a1 else a2
```

Also see

- GenerativeException

GenerativeException

In Standard ML, exception declarations are said to be *generative*, because each time an exception declaration is evaluated, it yields a new exception.

The following program demonstrates the generativity of exceptions.

```
exception E
val e1 = E
fun isE1 (e: exn): bool =
   case e of
      E => true
    | _ => false
exception E
val e2 = E
fun isE2 (e: exn): bool =
   case e of
      E => true
    | _ => false
fun pb (b: bool): unit =
   print (concat [Bool.toString b, "\n"])
val () = (pb (isE1 e1)
          ;pb (isE1 e2)
          ; pb (isE2 e1)
          ; pb (isE2 e2))
```

In the above program, two different exception declarations declare an exception `E` and a corresponding function that returns `true` only on that exception. Although declared by syntactically identical exception declarations, `e1` and `e2` are different exceptions. The program, when run, prints `true`, `false`, `false`, `true`.

A slight modification of the above program shows that even a single exception declaration yields a new exception each time it is evaluated.

```
fun f (): exn * (exn -> bool) =
   let
      exception E
   in
      (E, fn E => true | _ => false)
   end
val (e1, isE1) = f ()
val (e2, isE2) = f ()
fun pb (b: bool): unit =
   print (concat [Bool.toString b, "\n"])
val () = (pb (isE1 e1)
          ; pb (isE1 e2)
          ; pb (isE2 e1)
          ; pb (isE2 e2))
```

Each call to `f` yields a new exception and a function that returns `true` only on that exception. The program, when run, prints `true`, `false`, `false`, `true`.

Type Safety

Exception generativity is required for type safety. Consider the following valid SML program.

```
fun f (): ('a -> exn) * (exn -> 'a) =
   let
      exception E of 'a
   in
      (E, fn E x => x | _ => raise Fail "f")
```

```
   end
fun cast (a: 'a): 'b =
   let
      val (make: 'a -> exn, _) = f ()
      val (_, get: exn -> 'b) = f ()
   in
      get (make a)
   end
val _ = ((cast 13): int -> int) 14
```

If exceptions weren't generative, then each call `f ()` would yield the same exception constructor `E`. Then, our `cast` function could use `make:'a -> exn` to convert any value into an exception and then `get:exn -> 'b` to convert that exception to a value of arbitrary type. If `cast` worked, then we could cast an integer as a function and apply. Of course, because of generative exceptions, this program raises `Fail "f"`.

Applications

The `exn` type is effectively a universal type.

Also see

- GenerativeDatatype

Git

Git is a distributed version control system. The MLton project currently uses Git to maintain its source code.

Here are some online Git resources.

- Reference Manual
- ProGit, by Scott Chacon

Glade

Glade is a tool for generating Gtk user interfaces.

WesleyTerpstra is working on a Glade→mGTK converter.

- http://www.mlton.org/pipermail/mlton/2004-December/016865.html

Globalize

Globalize is an analysis pass for the SXML IntermediateLanguage, invoked from ClosureConvert.

Description

This pass marks values that are constant, allowing ClosureConvert to move them out to the top level so they are only evaluated once and do not appear in closures.

Implementation

- `globalize.sig`
- `globalize.fun`

Details and Notes

GnuMP

The GnuMP library (GNU Multiple Precision arithmetic library) is a library for arbitrary precision integer arithmetic. MLton uses the GnuMP library to implement the Basis Library `IntInf` module.

Known issues

- There is a known problem with the GnuMP library (prior to version 4.2.x), where it requires a lot of stack space for some computations, e.g. `IntInf.toString` of a million digit number. If you run with stack size limited, you may see a segfault in such programs. This problem is mentioned in the GnuMP FAQ, where they describe two solutions.
  - Increase (or unlimit) your stack space. From your program, use `setrlimit`, or from the shell, use `ulimit`.
  - Configure and rebuild `libgmp` with `--disable-alloca`, which will cause it to allocate temporaries using `malloc` instead of on the stack.
- On some platforms, the GnuMP library may be configured to use one of multiple ABIs (Application Binary Interfaces). For example, on some 32-bit architectures, GnuMP may be configured to represent a limb as either a 32-bit `long` or as a 64-bit `long long`. Similarly, GnuMP may be configured to use specific CPU features.

  In order to efficiently use the GnuMP library, MLton represents an `IntInf.int` value in a manner compatible with the GnuMP library's representation of a limb. Hence, it is important that MLton and the GnuMP library agree upon the representation of a limb.
  - When using a source package of MLton, building will detect the GnuMP library's representation of a limb.
  - When using a binary package of MLton that is dynamically linked against the GnuMP library, the build machine and the install machine must have the GnuMP library configured with the same representation of a limb. (On the other hand, the build machine need not have the GnuMP library configured with CPU features compatible with the install machine.)
  - When using a binary package of MLton that is statically linked against the GnuMP library, the build machine and the install machine need not have the GnuMP library configured with the same representation of a limb. (On the other hand, the build machine must have the GnuMP library configured with CPU features compatible with the install machine.)

    However, MLton will be configured with the representation of a limb from the GnuMP library of the build machine. Executables produced by MLton will be incompatible with the GnuMP library of the install machine. To *reconfigure* MLton with the representation of a limb from the GnuMP library of the install machine, one must edit:

    ```
    /usr/lib/mlton/self/sizes
    ```

    changing the

    ```
    mplimb = ??
    ```

    entry so that `??` corresponds to the bytes in a limb; and, one must edit:

    ```
    /usr/lib/mlton/sml/basis/config/c/arch-os/c-types.sml
    ```

    changing the

    ```
    (* from "gmp.h" *)
    structure C_MPLimb = struct open Word?? type t = word end
    functor C_MPLimb_ChooseWordN (A: CHOOSE_WORDN_ARG) = ChooseWordN_Word?? (A)
    ```

    entries so that `??` corresponds to the bits in a limb.

Google Summer of Code (2013)

Mentors

The following developers have agreed to serve as mentors for the 2013 Google Summer of Code:

- Matthew Fluet
- Lukasz (Luke) Ziarek
- Suresh Jagannathan

Ideas List

Implement a Partial Redundancy Elimination (PRE) Optimization

Partial redundancy elimination (PRE) is a program transformation that removes operations that are redundant on some, but not necessarily all paths, through the program. PRE can subsume both common subexpression elimination and loop-invariant code motion, and is therefore a potentially powerful optimization. However, a naïve implementation of PRE on a program in static single assignment (SSA) form is unlikely to be effective. This project aims to adapt and implement the SSAPRE algorithm(s) of Thomas VanDrunen in MLton's SSA intermediate language.

Background:

- Anticipation-based partial redundancy elimination for static single assignment form; Thomas VanDrunen and Antony L. Hosking
- Partial Redundancy Elimination for Global Value Numbering; Thomas VanDrunen
- Value-Based Partial Redundancy Elimination; Thomas VanDrunen and Antony L. Hosking
- Partial redundancy elimination in SSA form; Robert Kennedy, Sun Chan, Shin-Ming Liu, Raymond Lo, Peng Tu, and Fred Chow

Recommended Skills: SML programming experience; some middle-end compiler experience

Design and Implement a Heap Profiler

A heap profile is a description of the space usage of a program. A heap profile is concerned with the allocation, retention, and deallocation (via garbage collection) of heap data during the execution of a program. A heap profile can be used to diagnose performance problems in a functional program that arise from space leaks. This project aims to design and implement a heap profiler for MLton compiled programs.

Background:

- GCspy: an adaptable heap visualisation framework; Tony Printezis and Richard Jones
- New dimensions in heap profiling; Colin Runciman and Niklas Röjemo
- Heap profiling for space efficiency; Colin Runciman and Niklas Röjemo
- Heap profiling of lazy functional programs; Colin Runciman and David Wakeling

Recommended Skills: C and SML programming experience; some experience with UI and visualization

Garbage Collector Improvements

The garbage collector plays a significant role in the performance of functional languages. Garbage collect too often, and program performance suffers due to the excessive time spent in the garbage collector. Garbage collect not often enough, and program performance suffers due to the excessive space used by the uncollected garbage. One particular issue is ensuring that a program utilizing a garbage collector "plays nice" with other processes on the system, by not using too much or too little physical memory. While there are some reasonable theoretical results about garbage collections with heaps of fixed size, there seems to be insufficient work that really looks carefully at the question of dynamically resizing the heap in response to the live data demands of the application and, similarly, in response to the behavior of the operating system and other processes. This project aims to investigate improvements to the memory behavior of MLton compiled programs through better tuning of the garbage collector.

Background:

- Automated Heap Sizing in the Poly/ML Runtime (Position Paper); David White, Jeremy Singer, Jonathan Aitken, and David Matthews
- Isla Vista Heap Sizing: Using Feedback to Avoid Paging; Chris Grzegorczyk, Sunil Soman, Chandra Krintz, and Rich Wolski
- Controlling garbage collection and heap growth to reduce the execution time of Java applications; Tim Brecht, Eshrat Arjomandi, Chang Li, and Hang Pham
- Garbage collection without paging; Matthew Hertz, Yi Feng, and Emery D. Berger
- Automatic heap sizing: taking real memory into account; Ting Yang, Matthew Hertz, Emery D. Berger, Scott F. Kaplan, and J. Eliot B. Moss

Recommended Skills: C programming experience; some operating systems and/or systems programming experience; some compiler and garbage collector experience

Implement Successor ML Language Features

Any programming language, including Standard ML, can be improved. The community has identified a number of modest extensions and revisions to the Standard ML programming language that would likely prove useful in practice. This project aims to implement these language features in the MLton compiler.

Background:

- Successor ML
- HaMLet (Successor ML)
- A critique of Standard ML; Andrew W. Appel

Recommended Skills: SML programming experience; some front-end compiler experience (i.e., scanners and parsers)

Implement Source-level Debugging

Debugging is a fact of programming life. Unfortunately, most SML implementations (including MLton) provide little to no source-level debugging support. This project aims to add basic to intermediate source-level debugging support to the MLton compiler. MLton already supports source-level profiling, which can be used to attribute bytes allocated or time spent in source functions. It should be relatively straightforward to leverage this source-level information into basic source-level debugging support, with the ability to set/unset breakpoints and step through declarations and functions. It may be possible to also provide intermediate source-level debugging support, with the ability to inspect in-scope variables of basic types (e.g., types compatible with MLton's foreign function interface).

Background:

- MLton — How Profiling Works

- MLton — Foreign Function Interface Types
- DWARF Debugging Standard
- STABS Debugging Format

Recommended Skills: SML programming experience; some compiler experience

SIMD Primitives

Most modern processors offer some direct support for SIMD (Single Instruction, Multiple Data) operations, such as Intel's MMX/SSE instructions, AMD's 3DNow! instructions, and IBM's AltiVec. Such instructions are particularly useful for multimedia, scientific, and cryptographic applications. This project aims to add preliminary support for vector data and vector operations to the MLton compiler. Ideally, after surveying SIMD instruction sets and SIMD support in other compilers, a core set of SIMD primitives with broad architecture and compiler support can be identified. After adding SIMD primitives to the core compiler and carrying them through to the various backends, there will be opportunities to design and implement an SML library that exposes the primitives to the SML programmer as well as opportunities to design and implement auto-vectorization optimizations.

Background:

- SIMD
- Auto-vectorization in GCC
- Auto-vectorization in LLVM

Recommended Skills: SML programming experience; some compiler experience; some computer architecture experience

RTOS Support

This project entails porting the MLton compiler to RTOSs such as: RTEMS, RT Linux, and FreeRTOS. The project will include modifications to the MLton build and configuration process. Students will need to extend the MLton configuration process for each of the RTOSs. The MLton compilation process will need to be extended to invoke the C cross compilers the RTOSs provide for embedded support. Test scripts for validation will be necessary and these will need to be run in emulators for supported architectures.

Recommended Skills: C programming experience; some scripting experience

Region Based Memory Management

Region based memory management is an alternative automatic memory management scheme to garbage collection. Regions can be inferred by the compiler (e.g., Cyclone and MLKit) or provided to the programmer through a library. Since many students do not have extensive experience with compilers we plan on adopting the later approach. Creating a viable region based memory solution requires the removal of the GC and changes to the allocator. Additionally, write barriers will be necessary to ensure references between two ML objects is never established if the left hand side of the assignment has a longer lifetime than the right hand side. Students will need to come up with an appropriate interface for creating, entering, and exiting regions (examples include RTSJ scoped memory and SCJ scoped memory).

Background:

- Cyclone
- MLKit
- RTSJ + SCJ scopes

Recommended Skills: SML programming experience; C programming experience; some compiler and garbage collector experience

Integration of Multi-MLton

MultiMLton is a compiler and runtime environment that targets scalable multicore platforms. It is an extension of MLton. It combines new language abstractions and associated compiler analyses for expressing and implementing various kinds of fine-grained parallelism (safe futures, speculation, transactions, etc.), along with a sophisticated runtime system tuned to efficiently handle large numbers of lightweight threads. The core stable features of MultiMLton will need to be integrated with the latest MLton public release. Certain experimental features, such as support for the Intel SCC and distributed runtime will be omitted. This project requires students to understand the delta between the MultiMLton code base and the MLton code base. Students will need to create build and configuration scripts for MLton to enable MultiMLton features.

Background

- MultiMLton — Publications

Recommended Skills: SML programming experience; C programming experience; some compiler experience

Google Summer of Code (2014)

Mentors

The following developers have agreed to serve as mentors for the 2014 Google Summer of Code:

- Matthew Fluet
- Lukasz (Luke) Ziarek
- John Reppy
- KC Sivaramakrishnan

Ideas List

Implement a Partial Redundancy Elimination (PRE) Optimization

Partial redundancy elimination (PRE) is a program transformation that removes operations that are redundant on some, but not necessarily all paths, through the program. PRE can subsume both common subexpression elimination and loop-invariant code motion, and is therefore a potentially powerful optimization. However, a naïve implementation of PRE on a program in static single assignment (SSA) form is unlikely to be effective. This project aims to adapt and implement the SSAPRE algorithm(s) of Thomas VanDrunen in MLton's SSA intermediate language.

Background:

- Anticipation-based partial redundancy elimination for static single assignment form; Thomas VanDrunen and Antony L. Hosking
- Partial Redundancy Elimination for Global Value Numbering; Thomas VanDrunen
- Value-Based Partial Redundancy Elimination; Thomas VanDrunen and Antony L. Hosking
- Partial redundancy elimination in SSA form; Robert Kennedy, Sun Chan, Shin-Ming Liu, Raymond Lo, Peng Tu, and Fred Chow

Recommended Skills: SML programming experience; some middle-end compiler experience

Design and Implement a Heap Profiler

A heap profile is a description of the space usage of a program. A heap profile is concerned with the allocation, retention, and deallocation (via garbage collection) of heap data during the execution of a program. A heap profile can be used to diagnose performance problems in a functional program that arise from space leaks. This project aims to design and implement a heap profiler for MLton compiled programs.

Background:

- GCspy: an adaptable heap visualisation framework; Tony Printezis and Richard Jones
- New dimensions in heap profiling; Colin Runciman and Niklas Röjemo
- Heap profiling for space efficiency; Colin Runciman and Niklas Röjemo
- Heap profiling of lazy functional programs; Colin Runciman and David Wakeling

Recommended Skills: C and SML programming experience; some experience with UI and visualization

Garbage Collector Improvements

The garbage collector plays a significant role in the performance of functional languages. Garbage collect too often, and program performance suffers due to the excessive time spent in the garbage collector. Garbage collect not often enough, and program performance suffers due to the excessive space used by the uncollected garbage. One particular issue is ensuring that a program utilizing a garbage collector "plays nice" with other processes on the system, by not using too much or too little physical memory. While there are some reasonable theoretical results about garbage collections with heaps of fixed size, there seems to be insufficient work that really looks carefully at the question of dynamically resizing the heap in response to the live data demands of the application and, similarly, in response to the behavior of the operating system and other processes. This project aims to investigate improvements to the memory behavior of MLton compiled programs through better tuning of the garbage collector.

Background:

- Automated Heap Sizing in the Poly/ML Runtime (Position Paper); David White, Jeremy Singer, Jonathan Aitken, and David Matthews
- Isla Vista Heap Sizing: Using Feedback to Avoid Paging; Chris Grzegorczyk, Sunil Soman, Chandra Krintz, and Rich Wolski
- Controlling garbage collection and heap growth to reduce the execution time of Java applications; Tim Brecht, Eshrat Arjomandi, Chang Li, and Hang Pham
- Garbage collection without paging; Matthew Hertz, Yi Feng, and Emery D. Berger
- Automatic heap sizing: taking real memory into account; Ting Yang, Matthew Hertz, Emery D. Berger, Scott F. Kaplan, and J. Eliot B. Moss

Recommended Skills: C programming experience; some operating systems and/or systems programming experience; some compiler and garbage collector experience

Implement Successor ML Language Features

Any programming language, including Standard ML, can be improved. The community has identified a number of modest extensions and revisions to the Standard ML programming language that would likely prove useful in practice. This project aims to implement these language features in the MLton compiler.

Background:

- Successor ML
- HaMLet (Successor ML)
- A critique of Standard ML; Andrew W. Appel

Recommended Skills: SML programming experience; some front-end compiler experience (i.e., scanners and parsers)

Implement Source-level Debugging

Debugging is a fact of programming life. Unfortunately, most SML implementations (including MLton) provide little to no source-level debugging support. This project aims to add basic to intermediate source-level debugging support to the MLton compiler. MLton already supports source-level profiling, which can be used to attribute bytes allocated or time spent in source functions. It should be relatively straightforward to leverage this source-level information into basic source-level debugging support, with the ability to set/unset breakpoints and step through declarations and functions. It may be possible to also provide intermediate source-level debugging support, with the ability to inspect in-scope variables of basic types (e.g., types compatible with MLton's foreign function interface).

Background:

- MLton — How Profiling Works

- MLton — Foreign Function Interface Types
- DWARF Debugging Standard
- STABS Debugging Format

Recommended Skills: SML programming experience; some compiler experience

Region Based Memory Management

Region based memory management is an alternative automatic memory management scheme to garbage collection. Regions can be inferred by the compiler (e.g., Cyclone and MLKit) or provided to the programmer through a library. Since many students do not have extensive experience with compilers we plan on adopting the later approach. Creating a viable region based memory solution requires the removal of the GC and changes to the allocator. Additionally, write barriers will be necessary to ensure references between two ML objects is never established if the left hand side of the assignment has a longer lifetime than the right hand side. Students will need to come up with an appropriate interface for creating, entering, and exiting regions (examples include RTSJ scoped memory and SCJ scoped memory).

Background:

- Cyclone
- MLKit
- RTSJ + SCJ scopes

Recommended Skills: SML programming experience; C programming experience; some compiler and garbage collector experience

Integration of Multi-MLton

MultiMLton is a compiler and runtime environment that targets scalable multicore platforms. It is an extension of MLton. It combines new language abstractions and associated compiler analyses for expressing and implementing various kinds of fine-grained parallelism (safe futures, speculation, transactions, etc.), along with a sophisticated runtime system tuned to efficiently handle large numbers of lightweight threads. The core stable features of MultiMLton will need to be integrated with the latest MLton public release. Certain experimental features, such as support for the Intel SCC and distributed runtime will be omitted. This project requires students to understand the delta between the MultiMLton code base and the MLton code base. Students will need to create build and configuration scripts for MLton to enable MultiMLton features.

Background

- MultiMLton — Publications

Recommended Skills: SML programming experience; C programming experience; some compiler experience

Concurrent ML Improvements

Concurrent ML is an SML concurrency library based on synchronous message passing. MLton has a partial implementation of the CML message-passing primitives, but its use in real-world applications has been stymied by the lack of completeness and thread-safe I/O libraries. This project would aim to flesh out the CML implementation in MLton to be fully compatible with the "official" version distributed as part of SML/NJ. Furthermore, time permitting, runtime system support could be added to allow use of modern OS features, such as asynchronous I/O, in the implementation of CML's system interfaces.

Background

- http://cml.cs.uchicago.edu/
- http://mlton.org/ConcurrentML
- http://mlton.org/ConcurrentMLImplementation

Recommended Skills: SML programming experience; knowledge of concurrent programming; some operating systems and/or systems programming experience

Google Summer of Code (2015)

Mentors

The following developers have agreed to serve as mentors for the 2015 Google Summer of Code:

- Matthew Fluet
- Lukasz (Luke) Ziarek

Ideas List

Design and Implement a Heap Profiler

A heap profile is a description of the space usage of a program. A heap profile is concerned with the allocation, retention, and deallocation (via garbage collection) of heap data during the execution of a program. A heap profile can be used to diagnose performance problems in a functional program that arise from space leaks. This project aims to design and implement a heap profiler for MLton compiled programs.

Background:

- GCspy: an adaptable heap visualisation framework; Tony Printezis and Richard Jones
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Garbage Collector Improvements

The garbage collector plays a significant role in the performance of functional languages. Garbage collect too often, and program performance suffers due to the excessive time spent in the garbage collector. Garbage collect not often enough, and program performance suffers due to the excessive space used by the uncollected garbage. One particular issue is ensuring that a program utilizing a garbage collector "plays nice" with other processes on the system, by not using too much or too little physical memory. While there are some reasonable theoretical results about garbage collections with heaps of fixed size, there seems to be insufficient work that really looks carefully at the question of dynamically resizing the heap in response to the live data demands of the application and, similarly, in response to the behavior of the operating system and other processes. This project aims to investigate improvements to the memory behavior of MLton compiled programs through better tuning of the garbage collector.

Background:

- The Garbage Collection Handbook: The Art of Automatic Memory Management; Richard Jones, Antony Hosking, Eliot Moss
- Dual-Mode Garbage Collection; Patrick Sansom
- Automatic Heap Sizing: Taking Real Memory into Account; Ting Yang, Matthew Hertz, Emery D. Berger, Scott F. Kaplan, and J. Eliot B. Moss
- Controlling Garbage Collection and Heap Growth to Reduce the Execution Time of Java Applications; Tim Brecht, Eshrat Arjomandi, Chang Li, and Hang Pham
- Isla Vista Heap Sizing: Using Feedback to Avoid Paging; Chris Grzegorczyk, Sunil Soman, Chandra Krintz, and Rich Wolski
- The Economics of Garbage Collection; Jeremy Singer, Richard E. Jones, Gavin Brown, and Mikel Luján

- Automated Heap Sizing in the Poly/ML Runtime (Position Paper); David White, Jeremy Singer, Jonathan Aitken, and David Matthews
- Control Theory for Principled Heap Sizing; David R. White, Jeremy Singer, Jonathan M. Aitken, and Richard E. Jones

Recommended Skills: C programming experience; some operating systems and/or systems programming experience; some compiler and garbage collector experience

Heap-allocated Activation Records

Activation records (a.k.a., stack frames) are traditionally allocated on a stack. This naturally corresponds to the call-return pattern of function invocation. However, there are some disadvantages to stack-allocated activation records. In a functional programming language, functions may be deeply recursive, resulting in call stacks that are much larger than typically supported by the operating system; hence, a functional programming language implementation will typically store its stack in its heap. Furthermore, a functional programming language implementation must handle and recover from stack overflow, by allocating a larger stack (again, in its heap) and copying activation records from the old stack to the new stack. In the presence of threads, stacks must be allocated in a heap and, in the presence of a garbage collector, should be garbage collected when unreachable. While heap-allocated activation records avoid many of these disadvantages, they have not been widely implemented. This project aims to implement and evaluate heap-allocated activation records in the MLton compiler.

Background:

- Empirical and Analytic Study of Stack Versus Heap Cost for Languages with Closures; Andrew W. Appel and Zhong Shao
- Space-efficient closure representations; Zhong Shao and Andrew W. Appel
- Representing control in the presence of first-class continuations; R. Hieb, R. Kent Dybvig, and Carl Bruggeman

Recommended Skills: SML programming experience; some middle- and back-end compiler experience

Correctly Rounded Floating-point Binary-to-Decimal and Decimal-to-Binary Conversion Routines in Standard ML

The IEEE Standard for Floating-Point Arithmetic (IEEE 754) is the de facto representation for floating-point computation. However, it is a *binary* (base 2) representation of floating-point values, while many applications call for input and output of floating-point values in *decimal* (base 10) representation. The *decimal-to-binary* conversion problem takes a decimal floating-point representation (e.g., a string like `"0.1"`) and returns the best binary floating-point representation of that number. The *binary-to-decimal* conversion problem takes a binary floating-point representation and returns a decimal floating-point representation using the smallest number of digits that allow the decimal floating-point representation to be converted to the original binary floating-point representation. For both conversion routines, "best" is dependent upon the current floating-point rounding mode.

MLton uses David Gay's gdtoa library for floating-point conversions. While this is an exellent library, it generalizes the decimal-to-binary and binary-to-decimal conversion routines beyond what is required by the Standard ML Basis Library and induces an external dependency on the compiler. Native implementations of these conversion routines in Standard ML would obviate the dependency on the `gdtoa` library, while also being able to take advantage of Standard ML features in the implementation (e.g., the published algorithms often require use of infinite precision arithmetic, which is provided by the `IntInf` structure in Standard ML, but is provided in an ad hoc fasion in the `gdtoa` library).

This project aims to develop a native implementation of the conversion routines in Standard ML.

Background:

- What every computer scientist should know about floating-point arithmetic; David Goldberg
- How to print floating-point numbers accurately; Guy L. Steele, Jr. and Jon L. White
- How to read floating point numbers accurately; William D. Clinger
- Correctly Rounded Binary-Decimal and Decimal-Binary Conversions; David Gay

- Printing floating-point numbers quickly and accurately; Robert G. Burger and R. Kent Dybvig
- Printing floating-point numbers quickly and accurately with integers; Florian Loitsch

Recommended Skills: SML programming experience; algorithm design and implementation

Implement Source-level Debugging

Debugging is a fact of programming life. Unfortunately, most SML implementations (including MLton) provide little to no source-level debugging support. This project aims to add basic to intermediate source-level debugging support to the MLton compiler. MLton already supports source-level profiling, which can be used to attribute bytes allocated or time spent in source functions. It should be relatively straightforward to leverage this source-level information into basic source-level debugging support, with the ability to set/unset breakpoints and step through declarations and functions. It may be possible to also provide intermediate source-level debugging support, with the ability to inspect in-scope variables of basic types (e.g., types compatible with MLton's foreign function interface).

Background:

- MLton — How Profiling Works
- MLton — Foreign Function Interface Types
- DWARF Debugging Standard
- STABS Debugging Format

Recommended Skills: SML programming experience; some compiler experience

Region Based Memory Management

Region based memory management is an alternative automatic memory management scheme to garbage collection. Regions can be inferred by the compiler (e.g., Cyclone and MLKit) or provided to the programmer through a library. Since many students do not have extensive experience with compilers we plan on adopting the later approach. Creating a viable region based memory solution requires the removal of the GC and changes to the allocator. Additionally, write barriers will be necessary to ensure references between two ML objects is never established if the left hand side of the assignment has a longer lifetime than the right hand side. Students will need to come up with an appropriate interface for creating, entering, and exiting regions (examples include RTSJ scoped memory and SCJ scoped memory).

Background:

- Cyclone
- MLKit
- RTSJ + SCJ scopes

Recommended Skills: SML programming experience; C programming experience; some compiler and garbage collector experience

Adding Real-Time Capabilities

This project focuses on exposing real-time APIs from a real-time OS kernel at the SML level. This will require mapping the current MLton (or MultiMLton) threading framework to real-time threads that the RTOS provides. This will include associating priorities with MLton threads and building priority based scheduling algorithms. Additionally, support for perdioc, aperiodic, and sporadic tasks should be supported. A real-time SML library will need to be created to provide a forward facing interface for programmers. Stretch goals include reworking the MLton `atomic` statement and associated synchronization primitives built on top of the MLton `atomic` statement.

Recommended Skills: SML programming experience; C programming experience; real-time experience a plus but not required

Real-Time Garbage Collection

This project focuses on modifications to the MLton GC to support real-time garbage collection. We will model the real-time GC on the Schism RTGC. The first task will be to create a fixed size runtime object representation. Large structures will need to be represented as a linked lists of fixed sized objects. Arrays and vectors will be transferred into dense trees. Compaction and copying can therefore be removed from the GC algorithms that MLton currently supports. Lastly, the GC will be made concurrent, allowing for the execution of the GC threads as the lowest priority task in the system. Stretch goals include a priority aware mechanism for the GC to signal to real-time ML threads that it needs to scan their stack and identification of places where the stack is shallow to bound priority inversion during this procedure.

Recommended Skills: C programming experience; garbage collector experience a plus but not required

HaMLet

HaMLet is a Standard ML implementation. It is intended as reference implementation of The Definition of Standard ML (Revised) and not for serious practical work.

HenryCejtin

I was one of the original developers of Mathematica (actually employee #1). My background is a combination of mathematics and computer science. Currently I am doing various things in Chicago.

History

In April 1997, Stephen Weeks wrote a defunctorizer for Standard ML and integrated it with SML/NJ. The defunctorizer used SML/NJ's visible compiler and operated on the `Ast` intermediate representation produced by the SML/NJ front end. Experiments showed that defunctorization gave a speedup of up to six times over separate compilation and up to two times over batch compilation without functor expansion.

In August 1997, we began development of an independent compiler for SML. At the time the compiler was called `smlc`. By October, we had a working monomorphiser. By November, we added a polyvariant higher-order control-flow analysis. At that point, MLton was about 10,000 lines of code.

Over the next year and half, `smlc` morphed into a full-fledged compiler for SML. It was renamed MLton, and first released in March 1999.

From the start, MLton has been driven by whole-program optimization and an emphasis on performance. Also from the start, MLton has had a fast C FFI and `IntInf` based on the GNU multiprecision library. At its first release, MLton was 48,006 lines.

Between the March 1999 and January 2002, MLton grew to 102,541 lines, as we added a native code generator, mllex, mlyacc, a profiler, many optimizations, and many libraries including threads and signal handling.

During 2002, MLton grew to 112,204 lines and we had releases in April and September. We added support for cross compilation and used this to enable MLton to run on Cygwin/Windows and FreeBSD. We also made improvements to the garbage collector, so that it now works with large arrays and up to 4G of memory and so that it automatically uses copying, mark-compact, or generational collection depending on heap usage and RAM size. We also continued improvements to the optimizer and libraries.

During 2003, MLton grew to 122,299 lines and we had releases in March and July. We extended the profiler to support source-level profiling of time and allocation and to display call graphs. We completed the Basis Library implementation, and added new MLton-specific libraries for weak pointers and finalization. We extended the FFI to allow callbacks from C to SML. We added support for the Sparc/Solaris platform, and made many improvements to the C code generator.

HowProfilingWorks

Here's how Profiling works. If profiling is on, the front end (elaborator) inserts `Enter` and `Leave` statements into the source program for function entry and exit. For example,

```
fun f n = if n = 0 then 0 else 1 + f (n - 1)
```

becomes

```
fun f n =
   let
      val () = Enter "f"
      val res = (if n = 0 then 0 else 1 + f (n - 1))
                handle e => (Leave "f"; raise e)
      val () = Leave "f"
   in
      res
   end
```

Actually there is a bit more information than just the source function name; there is also lexical nesting and file position.

Most of the middle of the compiler ignores, but preserves, `Enter` and `Leave`. However, so that profiling preserves tail calls, the SSA shrinker has an optimization that notices when the only operations that cause a call to be a nontail call are profiling operations, and if so, moves them before the call, turning it into a tail call. If you observe a program that has a tail call that appears to be turned into a nontail when compiled with profiling, please report a bug.

There is the `checkProf` function in `type-check.fun`, which checks that the `Enter`/`Leave` statements match up.

In the backend, just before translating to the Machine IL, the profiler uses the `Enter`/`Leave` statements to infer the "local" portion of the control stack at each program point. The profiler then removes the `Enter`s/`Leave`s and inserts different information depending on which kind of profiling is happening. For time profiling (with the AMD64Codegen and X86Codegen), the profiler inserts labels that cover the code (i.e. each statement has a unique label in its basic block that prefixes it) and associates each label with the local control stack. For time profiling (with the CCodegen and LLVMCodegen), the profiler inserts code that sets a global field that records the local control stack. For allocation profiling, the profiler inserts calls to a C function that will maintain byte counts. With stack profiling, the profiler also inserts a call to a C function at each nontail call in order to maintain information at runtime about what SML functions are on the stack.

At run time, the profiler associates counters (either clock ticks or byte counts) with source functions. When the program finishes, the profiler writes the counts out to the `mlmon.out` file. Then, `mlprof` uses source information stored in the executable to associate the counts in the `mlmon.out` file with source functions.

For time profiling, the profiler catches the `SIGPROF` signal 100 times per second and increments the appropriate counter, determined by looking at the label prefixing the current program counter and mapping that to the current source function.

Caveats

There may be a few missed clock ticks or bytes allocated at the very end of the program after the data is written.

Profiling has not been tested with signals or threads. In particular, stack profiling may behave strangely.

Identifier

In Standard ML, there are syntactically two kinds of identifiers.

- Alphanumeric: starts with a letter or prime (') and is followed by letters, digits, primes and underbars (_).
  Examples: abc, ABC123, Abc_123, 'a.
- Symbolic: a sequence of the following

```
! % & $ # + - / : < = > ? @ | ~ ` ^ | *
```

  Examples: +=, <=, >>, $.

With the exception of =, reserved words can not be identifiers.

There are a number of different classes of identifiers, some of which have additional syntactic rules.

- Identifiers not starting with a prime.
  - value identifier (includes variables and constructors)
  - type constructor
  - structure identifier
  - signature identifier
  - functor identifier
- Identifiers starting with a prime.
  - type variable
- Identifiers not starting with a prime and numeric labels (1, 2, ...).
  - record label

Immutable

Immutable means not mutable and is an adjective meaning "can not be modified". Most values in Standard ML are immutable. For example, constants, tuples, records, lists, and vectors are all immutable.

ImperativeTypeVariable

In Standard ML, an imperative type variable is a type variable whose second character is a digit, as in `'1a` or `'2b`. Imperative type variables were used as an alternative to the ValueRestriction in an earlier version of SML, but no longer play a role. They are treated exactly as other type variables.

ImplementExceptions

ImplementExceptions is a pass for the SXML IntermediateLanguage, invoked from SXMLSimplify.

Description

This pass implements exceptions.

Implementation

- `implement-exceptions.fun`

Details and Notes

ImplementHandlers

ImplementHandlers is a pass for the RSSA IntermediateLanguage, invoked from RSSASimplify.

Description

This pass implements the (threaded) exception handler stack.

Implementation

- `implement-handlers.fun`

Details and Notes

ImplementProfiling

ImplementProfiling is a pass for the RSSA IntermediateLanguage, invoked from RSSASimplify.

Description

This pass implements profiling.

Implementation

- `implement-profiling.fun`

Details and Notes

See HowProfilingWorks.

ImplementSuffix

ImplementSuffix is a pass for the SXML IntermediateLanguage, invoked from SXMLSimplify.

Description

This pass implements the `TopLevel_setSuffix` primitive, which installs a function to exit the program.

Implementation

- `implement-suffix.fun`

Details and Notes

ImplementSuffix works by introducing a new `ref` cell to contain the function of type `unit -> unit` that should be called on program exit.

- The following code (appropriately alpha-converted) is appended to the beginning of the SXML program:

```
val z_0 =
  fn a_0 =>
  let
    val x_0 =
      "toplevel suffix not installed"
    val x_1 =
      MLton_bug (x_0)
  in
    x_1
  end
val topLevelSuffixCell =
  Ref_ref (z_0)
```

- Any occurrence of

```
val x_0 =
  TopLevel_setSuffix (f_0)
```

  is rewritten to

```
val x_0 =
  Ref_assign (topLevelSuffixCell, f_0)
```

- The following code (appropriately alpha-converted) is appended to the end of the SXML program:

```
val f_0 =
  Ref_deref (topLevelSuffixCell)
val z_0 =
  ()
val x_0 =
  f_0 z_0
```

InfixingOperators

Fixity specifications are not part of signatures in Standard ML. When one wants to use a module that provides functions designed to be used as infix operators there are several obvious alternatives:

- Use only prefix applications. Unfortunately there are situations where infix applications lead to considerably more readable code.
- Make the fixity declarations at the top-level. This may lead to collisions and may be unsustainable in a large project. Pollution of the top-level should be avoided.
- Make the fixity declarations at each scope where you want to use infix applications. The duplication becomes inconvenient if the operators are widely used. Duplication of code should be avoided.
- Use non-standard extensions, such as the ML Basis system to control the scope of fixity declarations. This has the obvious drawback of reduced portability.
- Reuse existing infix operator symbols (^, +, -, ...). This can be convenient when the standard operators aren't needed in the same scope with the new operators. On the other hand, one is limited to the standard operator symbols and the code may appear confusing.

None of the obvious alternatives is best in every case. The following describes a slightly less obvious alternative that can sometimes be useful. The idea is to approximate Haskell's special syntax for treating any identifier enclosed in grave accents (backquotes) as an infix operator. In Haskell, instead of writing the prefix application `f x y` one can write the infix application `` x `f` y ``.

Infixing operators

Let's first take a look at the definitions of the operators:

```
infix  3 <\     fun x <\ f = fn y => f (x, y)      (* Left section      *)
infix  3 \>     fun f \> y = f y                   (* Left application  *)
infixr 3 />     fun f /> y = fn x => f (x, y)      (* Right section     *)
infixr 3 </     fun x </ f = f x                   (* Right application *)

infix  2 o  (* See motivation below *)
infix  0 :=
```

The left and right sectioning operators, `<\` and `/>`, are useful in SML for partial application of infix operators. ML For the Working Programmer describes curried functions `secl` and `secr` for the same purpose on pages 179-181. For example,

```
List.map (op- /> y)
```

is a function for subtracting `y` from a list of integers and

```
List.exists (x <\ op=)
```

is a function for testing whether a list contains an `x`.

Together with the left and right application operators, `\>` and `</`, the sectioning operators provide a way to treat any binary function (i.e. a function whose domain is a pair) as an infix operator. In general,

```
x0 <\f1\> x1 <\f2\> x2 ... <\fN\> xN = fN (... f2 (f1 (x0, x1), x2) ..., xN)
```

and

```
xN </fN/> ... x2 </f2/> x1 </f1/> x0  =  fN (xN, ... f2 (x2, f1 (x1, x0)) ...)
```

Examples

As a fairly realistic example, consider providing a function for sequencing comparisons:

```
structure Order (* ... *) =
   struct
      (* ... *)
      val orWhenEq = fn (EQUAL, th) => th ()
                      | (other,  _) => other
      (* ... *)
   end
```

Using `orWhenEq` and the infixing operators, one can write a `compare` function for triples as

```
fun compare (fad, fbe, fcf) ((a, b, c), (d, e, f)) =
    fad (a, d) <\Order.orWhenEq\> `fbe (b, e) <\Order.orWhenEq\> `fcf (c, f)
```

where ` is defined as

```
fun `f x = fn () => f x
```

Although `orWhenEq` can be convenient (try rewriting the above without it), it is probably not useful enough to be defined at the top level as an infix operator. Fortunately we can use the infixing operators and don't have to.

Another fairly realistic example would be to use the infixing operators with the technique described on the Printf page. Assuming that you would have a `Printf` module binding `printf`, ` , and formatting combinators named `int` and `string`, you could write

```
let open Printf in
  printf (`"Here's an int "<\int\>" and a string "<\string\>".") 13 "foo" end
```

without having to duplicate the fixity declarations. Alternatively, you could write

```
P.printf (P.`"Here's an int "<\P.int\>" and a string "<\P.string\>".") 13 "foo"
```

assuming you have the made the binding

```
structure P = Printf
```

Application and piping operators

The left and right application operators may also provide some notational convenience on their own. In general,

```
f \> x1 \> ... \> xN = f x1 ... xN
```

and

```
xN </ ... </ x1 </ f = f x1 ... xN
```

If nothing else, both of them can eliminate parentheses. For example,

```
foo (1 + 2) = foo \> 1 + 2
```

The left and right application operators are related to operators that could be described as the right and left piping operators:

```
infix  1 >|     val op>| = op</       (* Left pipe *)
infixr 1 |<     val op|< = op\>       (* Right pipe *)
```

As you can see, the left and right piping operators, `>|` and `|<`, are the same as the right and left application operators, respectively, except the associativities are reversed and the binding strength is lower. They are useful for piping data through a sequence of operations. In general,

```
x >| f1 >| ... >| fN = fN (... (f1 x) ...) = (fN o ... o f1) x
```

and

```
fN |< ... |< f1 |< x = fN (... (f1 x) ...) = (fN o ... o f1) x
```

The right piping operator, `|<`, is provided by the Haskell prelude as `$`. It can be convenient in CPS or continuation passing style.

A use for the left piping operator is with parsing combinators. In a strict language, like SML, eta-reduction is generally unsafe. Using the left piping operator, parsing functions can be formatted conveniently as

```
fun parsingFunc input =
   input >| (* ... *)
         || (* ... *)
         || (* ... *)
```

where `||` is supposed to be a combinator provided by the parsing combinator library.

About precedences

You probably noticed that we redefined the precedences of the function composition operator `o` and the assignment operator `:=`. Doing so is not strictly necessary, but can be convenient and should be relatively safe. Consider the following motivating examples from Wesley W. Terpstra relying on the redefined precedences:

```
Word8.fromInt o Char.ord o s <\String.sub
(* Combining sectioning and composition *)

x := s <\String.sub\> i
(* Assigning the result of an infixed application *)
```

In imperative languages, assignment usually has the lowest precedence (ignoring statement separators). The precedence of `:=` in the Basis Library is perhaps unnecessarily high, because an expression of the form `r :=x` always returns a unit, which makes little sense to combine with anything. Dropping `:=` to the lowest precedence level makes it behave more like in other imperative languages.

The case for `o` is different. With the exception of `before` and `:=`, it doesn't seem to make much sense to use `o` with any of the operators defined by the Basis Library in an unparenthesized expression. This is simply because none of the other operators deal with functions. It would seem that the precedence of `o` could be chosen completely arbitrarily from the set `{1, ..., 9}` without having any adverse effects with respect to other infix operators defined by the Basis Library.

Design of the symbols

The closest approximation of Haskell's ``x `f` y`` syntax achievable in Standard ML would probably be something like ``x `f^ y``, but `^` is already used for string concatenation by the Basis Library. Other combinations of the characters `` ` `` and `^` would be possible, but none seems clearly the best visually. The symbols `<\`, `\>`, `</`, and `/>` are reasonably concise and have a certain self-documenting appearance and symmetry, which can help to remember them. As the names suggest, the symbols of the piping operators `>|` and `|<` are inspired by Unix shell pipelines.

Also see

- Utilities

Inline

Inline is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

This pass inlines SSA functions using a size-based metric.

Implementation

- `inline.sig`
- `inline.fun`

Details and Notes

The Inline pass can be invoked to use one of three metrics:

- `NonRecursive(product, small)` — inline any function satisfying `(numCalls -1) * (size -small) <=product`, where `numCalls` is the static number of calls to the function and `size` is the size of the function.
- `Leaf(size)` — inline any leaf function smaller than `size`
- `LeafNoLoop(size)` — inline any leaf function without loops smaller than `size`

InsertLimitChecks

InsertLimitChecks is a pass for the RSSA IntermediateLanguage, invoked from RSSASimplify.

Description

This pass inserts limit checks.

Implementation

- `limit-check.fun`

Details and Notes

InsertSignalChecks

InsertSignalChecks is a pass for the RSSA IntermediateLanguage, invoked from RSSASimplify.

Description

This pass inserts signal checks.

Implementation

- `limit-check.fun`

Details and Notes

Installation

MLton runs on a variety of platforms and is distributed in both source and binary form.

A .tgz or .tbz binary package can be extracted at any location, yielding README.adoc (this file), CHANGELOG.adoc, LICENSE, Makefile, bin/, lib/, and share/. The compiler and tools can be executed in-place (e.g., ./bin/mlton).

A small set of Makefile variables can be used to customize the binary package via make update:

- CC: Specify C compiler. Can be used for alternative tools (e.g., CC=clang or CC=gcc-7).
- WITH_GMP_DIR, WITH_GMP_INC_DIR, WITH_GMP_LIB_DIR: Specify GMP include and library paths, if not on default search paths. (If WITH_GMP_DIR is set, then WITH_GMP_INC_DIR defaults to $(WITH_GMP_DIR)/include and WITH_GMP_LIB_DIR defaults to $(WITH_GMP_DIR)/lib.)

For example:

```
$ make CC=clang WITH_GMP_DIR=/opt/gmp update
```

On typical platforms, installing MLton (after optionally performing make update) to /usr/local can be accomplished via:

```
$ make install
```

A small set of Makefile variables can be used to customize the installation:

- PREFIX: Specify the installation prefix.
- CC: Specify C compiler. Can be used for alternative tools (e.g., CC=clang or CC=gcc-7).
- WITH_GMP_DIR, WITH_GMP_INC_DIR, WITH_GMP_LIB_DIR: Specify GMP include and library paths, if not on default search paths. (If WITH_GMP_DIR is set, then WITH_GMP_INC_DIR defaults to $(WITH_GMP_DIR)/include and WITH_GMP_LIB_DIR defaults to $(WITH_GMP_DIR)/lib.)

For example:

```
$ make PREFIX=/opt/mlton install
```

Installation of MLton creates the following files and directories.

- *prefix*/bin/mllex
  The MLLex lexer generator.
- *prefix*/bin/mlnlffigen
  The ML-NLFFI tool.
- *prefix*/bin/mlprof
  A Profiling tool.
- *prefix*/bin/mlton
  A script to call the compiler. This script may be moved anywhere, however, it makes use of files in *prefix*/lib/mlton.
- *prefix*/bin/mlyacc
  The MLYacc parser generator.
- *prefix*/lib/mlton
  Directory containing libraries and include files needed during compilation.
- *prefix*/share/man/man1/{mllex,mlnlffigen,mlprof,mlton,mlyacc}.1
  Man pages.
- *prefix*/share/doc/mlton
  Directory containing the user guide for MLton, mllex, and mlyacc, as well as example SML programs (in the examples directory), and license information.

Hello, World!

Once you have installed MLton, create a file called `hello-world.sml` with the following contents.

```
print "Hello, world!\n";
```

Now create an executable, `hello-world`, with the following command.

```
mlton hello-world.sml
```

You can now run `hello-world` to verify that it works. There are more small examples in *prefix*`/share/doc/mlton/examples`.

Installation on Cygwin

When installing the Cygwin `tgz`, you should use Cygwin's `bash` and `tar`. The use of an archiving tool that is not aware of Cygwin's mounts will put the files in the wrong place.

IntermediateLanguage

MLton uses a number of intermediate languages in translating from the input source program to low-level code. Here is a list in the order which they are translated to.

- AST. Pretty close to the source.
- CoreML. Explicitly typed, no module constructs.
- XML. Polymorphic, HigherOrder.
- SXML. SimplyTyped, HigherOrder.
- SSA. SimplyTyped, FirstOrder.
- SSA2. SimplyTyped, FirstOrder.
- RSSA. Explicit data representations.
- Machine. Untyped register transfer language.

IntroduceLoops

IntroduceLoops is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

This pass rewrites any SSA function that calls itself in tail position into one with a local loop and no self tail calls.

A SSA function like

```
fun F (arg_0, arg_1) = L_0 ()
  ...
  L_16 (x_0)
    ...
    F (z_0, z_1) Tail
  ...
```

becomes

```
fun F (arg_0', arg_1') = loopS_0 ()
  loopS_0 ()
    loop_0 (arg_0', arg_1')
  loop_0 (arg_0, arg_1)
    L_0 ()
  ...
  L_16 (x_0)
    ...
    loop_0 (z_0, z_1)
  ...
```

Implementation

- `introduce-loops.fun`

Details and Notes

JesperLouisAndersen

Jesper Louis Andersen is an undergraduate student at DIKU, the department of computer science, Copenhagen university. His contributions to MLton are few, though he has made the port of MLton to the NetBSD and OpenBSD platforms.

His general interests in computer science are compiler theory, language theory, algorithms and datastructures and programming. His assets are his general knowledge of UNIX systems, knowledge of system administration, knowledge of operating system kernels; NetBSD in particular.

He was employed by the university as a system administrator for 2 years, which has set him back somewhat in his studies. Currently he is trying to learn mathematics (real analysis, general topology, complex functional analysis and algebra).

Projects using MLton

A register allocator

For internal use at a compiler course at DIKU. It is written in the literate programming style and implements the *Iterated Register Coalescing* algorithm by Lal George and Andrew Appel http://citeseer.ist.psu.edu/george96iterated.html. The status of the project is that it is unfinished. Most of the basic parts of the algorithm is done, but the interface to the students (simple) datatype takes some conversion.

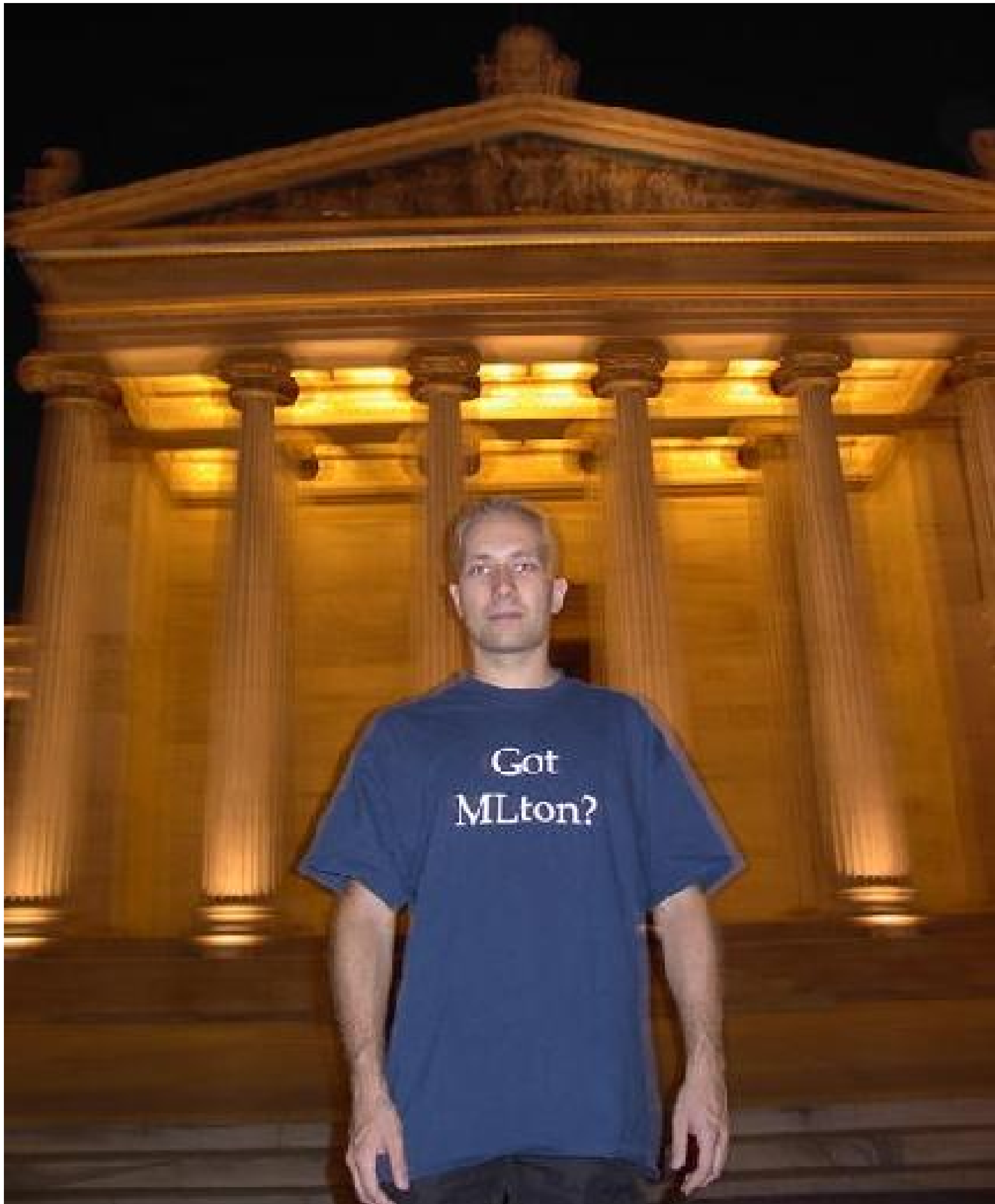
A configuration management system in SML

At this time, only loose plans exists for this. The plan is to build a Configuration Management system on the principles of the OpenCM system, see http://www.opencm.org/docs.html. The basic idea is to unify "naming" and "identity" into one by uniquely identifying all objects managed in the repository by the use of cryptographic checksums. This mantra guides the rest of the system, providing integrity, accessibility and confidentiality.

JohnnyAndersen

Johnny Andersen (aka Anoq of the Sun)

Here is a picture in front of the academy building at the University of Athens, Greece, taken in September 2003.



KnownCase

KnownCase is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

This pass duplicates and simplifies `Case` transfers when the constructor of the scrutinee is known.

Uses Restore.

For example, the program

```
val rec last =
  fn [] => 0
   | [x] => x
   | _ :: l => last l

val _ = 1 + last [2, 3, 4, 5, 6, 7]
```

gives rise to the SSA function

```
fun last_0 (x_142) = loopS_1 ()
  loopS_1 ()
    loop_11 (x_142)
  loop_11 (x_143)
    case x_143 of
      nil_1 => L_73 | ::_0 => L_74
  L_73 ()
    return global_5
  L_74 (x_145, x_144)
    case x_145 of
      nil_1 => L_75 | _ => L_76
  L_75 ()
    return x_144
  L_76 ()
    loop_11 (x_145)
```

which is simplified to

```
fun last_0 (x_142) = loopS_1 ()
  loopS_1 ()
    case x_142 of
      nil_1 => L_73 | ::_0 => L_118
  L_73 ()
    return global_5
  L_118 (x_230, x_229)
    L_74 (x_230, x_229, x_142)
  L_74 (x_145, x_144, x_232)
    case x_145 of
      nil_1 => L_75 | ::_0 => L_114
  L_75 ()
    return x_144
  L_114 (x_227, x_226)
    L_74 (x_227, x_226, x_145)
```

Implementation

- `known-case.fun`

Details and Notes

One interesting aspect of KnownCase, is that it often has the effect of unrolling list traversals by one iteration, moving the `nil`/`::` check to the end of the loop, rather than the beginning.

LambdaCalculus

The lambda calculus is the formal system underlying Standard ML.

LambdaFree

LambdaFree is an analysis pass for the SXML IntermediateLanguage, invoked from ClosureConvert.

Description

This pass descends the entire SXML program and attaches a property to each `Lambda` `PrimExp.t` in the program. Then, you can use `lambdaFree` and `lambdaRec` to get free variables of that `Lambda`.

Implementation

- `lambda-free.sig`
- `lambda-free.fun`

Details and Notes

For `Lambda`-s bound in a `Fun` dec, `lambdaFree` gives the union of the frees of the entire group of mutually recursive functions. Hence, `lambdaFree` for every `Lambda` in a single `Fun` dec is the same. Furthermore, for a `Lambda` bound in a `Fun` dec, `lambdaRec` gives the list of other functions bound in the same dec defining that `Lambda`.

For example:

```
val rec f = fn x => ... y ... g ... f ...
and g = fn z => ... f ... w ...
```

```
lambdaFree(fn x =>) = [y, w]
lambdaFree(fn z =>) = [y, w]
lambdaRec(fn x =>) = [g, f]
lambdaRec(fn z =>) = [f]
```

LanguageChanges

We are sometimes asked to modify MLton to change the language it compiles. In short, we are conservative about making such changes. There are a number of reasons for this.

- The Definition of Standard ML is an extremely high standard of specification. The value of the Definition would be significantly diluted by changes that are not specified at an equally high level, and the dilution increases with the complexity of the language change and its interaction with other language features.
- The SML community is small and there are a number of SML implementations. Without an agreed-upon standard, it becomes very difficult to port programs between compilers, and the community would be balkanized.
- Our main goal is to enable programmers to be as effective as possible with MLton/SML. There are a number of improvements other than language changes that we could spend our time on that would provide more benefit to programmers.
- The more the language that MLton compiles changes over time, the more difficult it is to use MLton as a stable platform for serious program development.

Despite these drawbacks, we have extended SML in a couple of cases.

- Foreign function interface
- ML Basis system
- Successor ML features

We allow these language extensions because they provide functionality that is impossible to achieve without them or have non-trivial community support. The Definition does not define a foreign function interface. So, we must either extend the language or greatly restrict the class of programs that can be written. Similarly, the Definition does not provide a mechanism for namespace control at the module level, making it impossible to deliver packaged libraries and have a hope of users using them without name clashes. The ML Basis system addresses this problem. We have also provided a formal specification of the ML Basis system at the level of the Definition.

Also see

- http://www.mlton.org/pipermail/mlton/2004-August/016165.html
- http://www.mlton.org/pipermail/mlton-user/2004-December/000320.html

Lazy

In a lazy (or non-strict) language, the arguments to a function are not evaluated before calling the function. Instead, the arguments are suspended and only evaluated by the function if needed.

Standard ML is an eager (or strict) language, not a lazy language. However, it is easy to delay evaluation of an expression in SML by creating a *thunk*, which is a nullary function. In SML, a thunk is written `fn () => e`. Another essential feature of laziness is *memoization*, meaning that once a suspended argument is evaluated, subsequent references look up the value. We can express this in SML with a function that maps a thunk to a memoized thunk.

```
signature LAZY =
   sig
      val lazy: (unit -> 'a) -> unit -> 'a
   end
```

This is easy to implement in SML.

```
structure Lazy: LAZY =
   struct
      fun lazy (th: unit -> 'a): unit -> 'a =
         let
            datatype 'a lazy_result = Unevaluated of (unit -> 'a)
                                    | Evaluated of 'a
                                    | Failed of exn

            val r = ref (Unevaluated th)
         in
            fn () =>
               case !r of
                   Unevaluated th => let
                                       val a  = th ()
                                           handle x => (r := Failed x; raise x)
                                       val () =          r := Evaluated a
                                    in
                                       a
                                    end
                 | Evaluated a => a
                 | Failed x    => raise x
         end
   end
```

Libraries

In theory every strictly conforming Standard ML program should run on MLton. However, often large SML projects use implementation specific features so some "porting" is required. Here is a partial list of software that is known to run on MLton.

- Utility libraries:
  - SMLNJLibrary - distributed with MLton
  - MLtonLibraryProject - various libraries located on the MLton subversion repository
  - `mlton` - the internal MLton utility library, which we hope to cleanup and make more accessible someday
  - sml-ext, a grab bag of libraries for MLton and other SML implementations (by Sean McLaughlin)
  - sml-lib, a grab bag of libraries for MLton and other SML implementations (by TomMurphy)
- Scanner generators:
  - MLLPTLibrary - distributed with MLton
  - MLLex - distributed with MLton
  - MLULex -
- Parser generators:
  - MLAntlr -
  - MLLPTLibrary - distributed with MLton
  - MLYacc - distributed with MLton
- Concurrency: ConcurrentML - distributed with MLton
- Graphics
  - SML3d
  - mGTK
- Misc. libraries:
  - CKitLibrary - distributed with MLton
  - MLRISCLibrary - distributed with MLton
  - ML-NLFFI - distributed with MLton
  - Swerve, an HTTP server
  - fxp, an XML parser

Ports in progress

Contact us for details on any of these.

- MLDoc http://people.cs.uchicago.edu/%7Ejhr/tools/ml-doc.html
- Unicode

More

More projects using MLton can be seen on the Users page.

Software for SML implementations other than MLton

- PostgreSQL
  - Moscow ML: http://www.dina.kvl.dk/%7Esestoft/mosmllib/Postgres.html
  - SML/NJ NLFFI: http://smlweb.sourceforge.net/smlsql/
- Web:
  - ML Kit: SMLserver (a plugin for AOLserver)
  - Moscow ML: ML Server Pages (support for PHP-style CGI scripting)
  - SML/NJ: smlweb

LibrarySupport

MLton supports both linking to and creating system-level libraries. While Standard ML libraries should be designed with the MLBasis system to work with other Standard ML programs, system-level library support allows MLton to create libraries for use by other programming languages. Even more importantly, system-level library support allows MLton to access libraries from other languages. This article will explain how to use libraries portably with MLton.

The Basics

A Dynamic Shared Object (DSO) is a piece of executable code written in a format understood by the operating system. Executable programs and dynamic libraries are the two most common examples of a DSO. They are called shared because if they are used more than once, they are only loaded once into main memory. For example, if you start two instances of your web browser (an executable), there may be two processes running, but the program code of the executable is only loaded once. A dynamic library, for example a graphical toolkit, might be used by several different executable programs, each possibly running multiple times. Nevertheless, the dynamic library is only loaded once and it's program code is shared between all of the processes.

In addition to program code, DSOs contain a table of textual strings called symbols. These are used in order to make the DSO do something useful, like execute. For example, on linux the symbol `_start` refers to the point in the program code where the operating system should start executing the program. Dynamic libraries generally provide many symbols, corresponding to functions which can be called and variables which can be read or written. Symbols can be used by the DSO itself, or by other DSOs which require services.

When a DSO creates a symbol, this is called *exporting*. If a DSO needs to use a symbol, this is called *importing*. A DSO might need to use symbols defined within itself or perhaps from another DSO. In both cases, it is importing that symbol, but the scope of the import differs. Similarly, a DSO might export a symbol for use only within itself, or it might export a symbol for use by other DSOs. Some symbols are resolved at compile time by the linker (those used within the DSO) and some are resolved at runtime by the dynamic link loader (symbols accessed between DSOs).

Symbols in MLton

Symbols in MLton are both imported and exported via the ForeignFunctionInterface. The notation `_import "symbolname"` imports functions, `_symbol "symbolname"` imports variables, and `_address "symbolname"` imports an address. To create and export a symbol, `_export "symbolname"` creates a function symbol and `_symbol "symbolname" 'alloc'` creates and exports a variable. For details of the syntax and restrictions on the supported FFI types, read the ForeignFunctionInterface page. In this discussion it only matters that every FFI use is either an import or an export.

When exporting a symbol, MLton supports controlling the export scope. If the symbol should only be used within the same DSO, that symbol has *`private`* scope. Conversely, if the symbol should also be available to other DSOs the symbol has *`public`* scope. Generally, one should have as few public exports as possible. Since they are public, other DSOs will come to depend on them, limiting your ability to change them. You specify the export scope in MLton by putting `private` or `public` after the symbol's name in an FFI directive. eg: `_export "foo" private:int->int;` or `_export "bar" public:int->int;` .

For technical reasons, the linker and loader on various platforms need to know the scope of a symbol being imported. If the symbol is exported by the same DSO, use `public` or `private` as appropriate. If the symbol is exported by a different DSO, then the scope *`external`* should be used to import it. Within a DSO, all references to a symbol must use the same scope. MLton will check this at compile time, reporting: `symbol "foo" redeclared as public (previously external)`. This may cause linker errors. However, MLton can only check usage within Standard ML. All objects being linked into a resulting DSO must agree, and it is the programmer's responsibility to ensure this.

Summary of symbol scopes:

- `private`: used for symbols exported within a DSO only for use within that DSO
- `public`: used for symbols exported within a DSO that may also be used outside that DSO
- `external`: used for importing symbols from another DSO
- All uses of a symbol within a DSO (both imports and exports) must agree on the symbol scope

Output Formats

MLton can create executables (`-format executable`) and dynamic shared libraries (`-format library`). To link a shared library, use `-link-opt -l<dso_name>`. The default output format is executable.

MLton can also create archives. An archive is not a DSO, but it does have a collection of symbols. When an archive is linked into a DSO, it is completely absorbed. Other objects being compiled into the DSO should refer to the public symbols in the archive as public, since they are still in the same DSO. However, in the interest of modular programming, private symbols in an archive cannot be used outside of that archive, even within the same DSO.

Although both executables and libraries are DSOs, some implementation details differ on some platforms. For this reason, MLton can create two types or archives. A normal archive (`-format archive`) is appropriate for linking into an executable. Conversely, a libarchive (`-format libarchive`) should be used if it will be linked into a dynamic library.

When MLton does not create an executable, it creates two special symbols. The symbol `libname_open` is a function which must be called before any other symbols are accessed. The `libname` is controlled by the `-libname` compile option and defaults to the name of the output, with any prefixing lib stripped (eg: `foo` → `foo`, `libfoo` → `foo`). The symbol `libname_close` is a function which should be called to clean up memory once done.

Summary of `-format` options:

- `executable`: create an executable (a DSO)
- `library`: create a dynamic shared library (a DSO)
- `archive`: create an archive of symbols (not a DSO) that can be linked into an executable
- `libarchive`: create an archive of symbols (not a DSO) that can be linked into a library

Related options:

- `-libname x`: controls the name of the special `_open` and `_close` functions.

Interfacing with C

MLton can generate a C header file. When the output format is not an executable, it creates one by default named `libname.h`. This can be overridden with `-export-header foo.h`. This header file should be included by any C files using the exported Standard ML symbols.

If C is being linked with Standard ML into the same output archive or DSO, then the C code should `#define PART_OF_LIBNAME` before it includes the header file. This ensures that the C code is using the symbols with correct scope. Any symbols exported from C should also be marked using the `PRIVATE`/`PUBLIC`/`EXTERNAL` macros defined in the Standard ML export header. The declared C scope on exported C symbols should match the import scope used in Standard ML.

An example:

```
#define PART_OF_FOO
#include "foo.h"

PUBLIC int cFoo() {
  return smlFoo();
}
```

```
val () = _export "smlFoo" private: unit -> int; (fn () => 5)
val cFoo = _import "cFoo" public: unit -> int;
```

Operating-system specific details

On Windows, `libarchive` and `archive` are the same. However, depending on this will lead to portability problems. Windows is also especially sensitive to mixups of *`public`* and *`external`*. If an archive is linked, make sure it's symbols are imported as `public`. If a DLL is linked, make sure it's symbols are imported as `external`. Using `external` instead of `public` will result in link errors that `__imp__foo is undefined`. Using `public` instead of `external` will result in inconsistent function pointer addresses and failure to update the imported variables.

On Linux, `libarchive` and `archive` are different. Libarchives are quite rare, but necessary if creating a library from an archive. It is common for a library to provide both an archive and a dynamic library on this platform. The linker will pick one or the other, usually preferring the dynamic library. While a quirk of the operating system allows external import to work for both archives and libraries, portable projects should not depend on this behaviour. On other systems it can matter how the library is linked (static or dynamic).

License

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```
../../LICENSE
```

LineDirective

To aid in the debugging of code produced by program generators such as Noweb, MLton supports comments with line directives of the form

```
(*#line l.c "f"*)
```

Here, *l* and *c* are sequences of decimal digits and *f* is the source file. The first character of a source file has the position 1.1. A line directive causes the front end to believe that the character following the right parenthesis is at the line and column of the specified file. A line directive only affects the reporting of error messages and does not affect program semantics (except for functions like `MLton.Exn.history` that report source file positions). Syntactically invalid line directives are ignored. To prevent incompatibilities with SML, the file name may not contain the character sequence `*)`.

LLVM

The LLVM Project is a collection of modular and reusable compiler and toolchain technologies.

MLton supports code generation via LLVM (`-codegen llvm`); see LLVMCodegen.

Also see

- CMinusMinus

LLVMCodegen

The LLVMCodegen is a code generator that translates the Machine IntermediateLanguage to LLVM assembly, which is further optimized and compiled to native object code by the LLVM toolchain.

It requires LLVM version 3.7 or greater to be installed.

In benchmarks performed on the AMD64 architecture, code size with this generator is usually slightly smaller than either the native or the C code generators. Compile time is worse than native, but slightly better than C. Run time is often better than either native or C.

Implementation

- `llvm-codegen.sig`
- `llvm-codegen.fun`

Details and Notes

The LLVMCodegen was initially developed by Brian Leibig (see An LLVM Back-end for MLton).

LocalFlatten

LocalFlatten is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

This pass flattens arguments to SSA blocks.

A block argument is flattened as long as it only flows to selects and there is some tuple constructed in this function that flows to it.

Implementation

- `local-flatten.fun`

Details and Notes

LocalRef

LocalRef is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

This pass optimizes `ref` cells local to a SSA function:

- global `ref`-s only used in one function are moved to the function
- `ref`-s only created, read from, and written to (i.e., don't escape) are converted into function local variables

Uses Multi and Restore.

Implementation

- `local-ref.fun`

Details and Notes

Moving a global `ref` requires the Multi analysis, because a global `ref` can only be moved into a function that is executed at most once.

Conversion of non-escaping `ref`-s is structured in three phases:

- analysis — a variable `r =Ref_ref x` escapes if
  - `r` is used in any context besides `Ref_assign (r, _)` or `Ref_deref r`
  - all uses `r` reachable from a (direct or indirect) call to `Thread_copyCurrent` are of the same flavor (either `Ref_assign` or `Ref_deref`); this also requires the Multi analysis.
- transformation
  - rewrites `r =Ref_ref x` to `r =x`
  - rewrites `_ =Ref_assign (r, y)` to `r =y`
  - rewrites `z =Ref_deref r` to `z =r`

  Note that the resulting program violates the SSA condition.
- Restore — restore the SSA condition.

Logo

Files

- mlton.svg
- mlton-1024.png
- mlton-512.png
- mlton-256.png
- mlton-128.png
- mlton-64.png
- mlton-32.png

LoopInvariant

LoopInvariant is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

This pass removes loop invariant arguments to local loops.

```
loop (x, y)
  ...
...
  loop (x, z)
...
```

becomes

```
loop' (x, y)
  loop (y)
loop (y)
  ...
...
  loop (z)
...
```

Implementation

- `loop-invariant.fun`

Details and Notes

LoopUnroll

LoopUnroll is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

A simple loop unrolling optimization.

Implementation

- `loop-unroll.fun`

Details and Notes

LoopUnswitch

LoopUnswitch is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

A simple loop unswitching optimization.

Implementation

- `loop-unswitch.fun`

Details and Notes

Machine

Machine is an IntermediateLanguage, translated from RSSA by ToMachine and used as input by the Codegen.

Description

Machine is an Untyped IntermediateLanguage, corresponding to a abstract register machine.

Implementation

- `machine.sig`
- `machine.fun`

Type Checking

The Machine IntermediateLanguage has a primitive type checker (`machine.sig`, `machine.fun`), which only checks some liveness properties.

Details and Notes

The runtime structure sets some constants according to the configuration files on the target architecture and OS.

ManualPage

MLton is run from the command line with a collection of options followed by a file name and a list of files to compile, assemble, and link with.

```
mlton [option ...] file.{c|mlb|o|sml} [file.{c|o|s|S} ...]
```

The simplest case is to run `mlton foo.sml`, where `foo.sml` contains a valid SML program, in which case MLton compiles the program to produce an executable `foo`. Since MLton does not support separate compilation, the program must be the entire program you wish to compile. However, the program may refer to signatures and structures defined in the Basis Library.

Larger programs, spanning many files, can be compiled with the ML Basis system. In this case, `mlton foo.mlb` will compile the complete SML program described by the basis `foo.mlb`, which may specify both SML files and additional bases.

Next Steps

- CompileTimeOptions
- RunTimeOptions

MatchCompilation

Match compilation is the process of translating an SML match into a nested tree (or dag) of simple case expressions and tests. MLton's match compiler is described here.

Match compilation in other compilers

- BaudinetMacQueen85
- Leroy90, pages 60-69.
- Sestoft96
- ScottRamsey00

MatchCompile

MatchCompile is a translation pass, agnostic in the IntermediateLanguages between which it translates.

Description

Match compilation converts a case expression with nested patterns into a case expression with flat patterns.

Implementation

- match-compile.sig
- match-compile.fun

Details and Notes

```
val matchCompile:
   {caseType: Type.t, (* type of entire expression *)
    cases: (NestedPat.t * ((Var.t -> Var.t) -> Exp.t)) vector,
    conTycon: Con.t -> Tycon.t,
    region: Region.t,
    test: Var.t,
    testType: Type.t,
    tyconCons: Tycon.t -> {con: Con.t, hasArg: bool} vector}
   -> Exp.t * (unit -> ((Layout.t * {isOnlyExns: bool}) vector) vector)
```

`matchCompile` is complicated by the desire for modularity between the match compiler and its caller. Its caller is responsible for building the right hand side of a rule `p => e`. On the other hand, the match compiler is responsible for destructing the test and binding new variables to the components. In order to connect the new variables created by the match compiler with the variables in the pattern `p`, the match compiler passes an environment back to its caller that maps each variable in `p` to the corresponding variable introduced by the match compiler.

The match compiler builds a tree of n-way case expressions by working from outside to inside and left to right in the patterns. For example,

```
case x of
   (_, C1 a) => e1
| (C2 b, C3 c) => e2
```

is translated to

```
let
   fun f1 a = e1
   fun f2 (b, c) = e2
in
  case x of
     (x1, x2) =>
       (case x1 of
          C2 b' => (case x2 of
                      C1 a' => f1 a'
                    | C3 c' => f2(b',c')
                    | _ => raise Match)
        | _ => (case x2 of
                  C1 a_ => f1 a_
                | _ => raise Match))
end
```

Here you can see the necessity of abstracting out the ride hand sides of the cases in order to avoid code duplication. Right hand sides are always abstracted. The simplifier cleans things up. You can also see the new (primed) variables introduced by the match compiler and how the renaming works. Finally, you can see how the match compiler introduces the necessary default clauses in order to make a match exhaustive, i.e. cover all the cases.

The match compiler uses `numCons` and `tyconCons` to determine the exhaustivity of matches against constructors.

MatthewFluet

Matthew Fluet (matthew.fluet@gmail.com , http://www.cs.rit.edu/%7Emtf) is an Assistant Professor at the Rochester Institute of Technology.

Current MLton projects:

- general maintenance
- release new version

Misc. and underspecified TODOs:

- understand RefFlatten and DeepFlatten
  - http://www.mlton.org/pipermail/mlton/2005-April/026990.html
  - http://www.mlton.org/pipermail/mlton/2007-November/030056.html
  - http://www.mlton.org/pipermail/mlton/2008-April/030250.html
  - http://www.mlton.org/pipermail/mlton/2008-July/030279.html
  - http://www.mlton.org/pipermail/mlton/2008-August/030312.html
  - http://www.mlton.org/pipermail/mlton/2008-September/030360.html
  - http://www.mlton.org/pipermail/mlton-user/2009-June/001542.html
- `MSG_DONTWAIT` isn't Posix
- coordinate w/ Dan Spoonhower and Lukasz Ziarek and Armand Navabi on multi-threaded
  - http://www.mlton.org/pipermail/mlton/2008-March/030214.html
- Intel Research bug: `no tyconRep property` (company won't release sample code)
  - http://www.mlton.org/pipermail/mlton-user/2008-March/001358.html
- treatment of real constants
  - http://www.mlton.org/pipermail/mlton/2008-May/030262.html
  - http://www.mlton.org/pipermail/mlton/2008-June/030271.html
- representation of `bool` and `_bool` in ForeignFunctionInterface
  - http://www.mlton.org/pipermail/mlton/2008-May/030264.html
- http://www.icfpcontest.org
  - John Reppy claims that "It looks like the card-marking overhead that one incurs when using generational collection swamps the benefits of generational collection."
- page to disk policy / single heap
  - http://www.mlton.org/pipermail/mlton/2008-June/030278.html
  - http://www.mlton.org/pipermail/mlton/2008-August/030318.html
- `MLton.GC.pack` doesn't keep a small heap if a garbage collection occurs before `MLton.GC.unpack`.

  - It might be preferable for `MLton.GC.pack` to be implemented as a (new) `MLton.GC.Ratios.setLive 1.1` followed by `MLton.GC.collect ()` and for `MLton.GC.unpack` to be implemented as `MLton.GC.Ratios.setLive 8.0` followed by `MLton.GC.collect ()`.

- The `static struct GC_objectType objectTypes[] =` array includes many duplicates. Objects of distinct source type, but equivalent representations (in terms of size, bytes non-pointers, number pointers) can share the objectType index.

- PolySpace bug: Redundant optimization (company won't release sample code)

  - http://www.mlton.org/pipermail/mlton/2008-September/030355.html

- treatment of exception raised during BasisLibrary evaluation

  - http://www.mlton.org/pipermail/mlton/2008-December/030501.html
  - http://www.mlton.org/pipermail/mlton/2008-December/030502.html
  - http://www.mlton.org/pipermail/mlton/2008-December/030503.html

- Use `memcpy`

  - http://www.mlton.org/pipermail/mlton-user/2009-January/001506.html
  - http://www.mlton.org/pipermail/mlton/2009-January/030506.html

- Implement more 64bit primops in x86 codegen

  - http://www.mlton.org/pipermail/mlton/2009-January/030507.html

- Enrich path-map file syntax:

  - http://www.mlton.org/pipermail/mlton/2008-September/030348.html
  - http://www.mlton.org/pipermail/mlton-user/2009-January/001507.html

- PolySpace bug: crash during Cheney-copy collection

  - http://www.mlton.org/pipermail/mlton/2009-February/030513.html

- eliminate `-build-constants`

  - all `_const`-s are known by `runtime/gen/basis-ffi.def`
  - generate `gen-constants.c` from `basis-ffi.def`
  - generate `constants` from `gen-constants.c` and `libmlton.a`
  - similar to `gen-sizes.c` and `sizes`

- eliminate "Windows hacks" for Cygwin from `Path` module

  - http://www.mlton.org/pipermail/mlton/2009-July/030606.html

- extend IL type checkers to check for empty property lists

- make (unsafe) `IntInf` conversions into primitives

  - http://www.mlton.org/pipermail/mlton/2009-July/030622.html

mGTK

mGTK is a wrapper for GTK+, a GUI toolkit.

We recommend using mGTK 0.93, which is not listed on their home page, but is available at the file release page. To test it, after unpacking, do `cd examples;make mlton`, after which you should be able to run the many examples (`signup-mlton`, `listview-mlton`, ...).

Also see

- Glade

MichaelNorrish

I am a researcher at NICTA, with a web-page here.

I'm interested in MLton because of the chance that it might be a good vehicle for future implementations of the HOL theorem-proving system. It's beginning to look as if one route forward will be to embed an SML interpreter into a MLton-compiled executable. I don't know if an extensible interpreter of the kind we're looking for already exists.

MikeThomas

Here is a picture at home in Brisbane, Queensland, Australia, taken in January 2004.

ML

ML stands for *meta language*. ML was originally designed in the 1970s as a programming language to assist theorem proving in the logic LCF. In the 1980s, ML split into two variants, Standard ML and OCaml, both of which are still used today.

MLAntlr

MLAntlr is a parser generator for Standard ML.

Also see

- MLULex
- MLLPTLibrary

MLBasis

The ML Basis system extends Standard ML to support programming-in-the-very-large, namespace management at the module level, separate delivery of library sources, and more. While Standard ML modules are a sophisticated language for programming-in-the-large, it is difficult, if not impossible, to accomplish a number of routine namespace management operations when a program draws upon multiple libraries provided by different vendors.

The ML Basis system is a simple, yet powerful, approach that builds upon the programmer's intuitive notion (and The Definition of Standard ML (Revised)'s formal notion) of the top-level environment (a *basis*). The system is designed as a natural extension of Standard ML; the formal specification of the ML Basis system (`mlb-formal.pdf`) is given in the style of the Definition.

Here are some of the key features of the ML Basis system:

1. Explicit file order: The order of files (and, hence, the order of evaluation) in the program is explicit. The ML Basis system's semantics are structured in such a way that for any well-formed project, there will be exactly one possible interpretation of the project's syntax, static semantics, and dynamic semantics.
2. Implicit dependencies: A source file (corresponding to an SML top-level declaration) is elaborated in the environment described by preceding declarations. It is not necessary to explicitly list the dependencies of a file.
3. Scoping and renaming: The ML Basis system provides mechanisms for limiting the scope of (i.e, hiding) and renaming identifiers.
4. No naming convention for finding the file that defines a module. To import a module, its defining file must appear in some ML Basis file.

Next steps

- MLBasisSyntaxAndSemantics
- MLBasisExamples
- MLBasisPathMap
- MLBasisAnnotations
- MLBasisAvailableLibraries

MLBasisAnnotationExamples

Here are some example uses of MLBasisAnnotations.

Eliminate spurious warnings in automatically generated code

Programs that automatically generate source code can often produce nonexhaustive patterns, relying on invariants of the generated code to ensure that the pattern matchings never fail. A programmer may wish to elide the nonexhaustive warnings from this code, in order that legitimate warnings are not missed in a flurry of false positives. To do so, the programmer simply annotates the generated code with the `nonexhaustiveBind ignore` and `nonexhaustiveMatch ignore` annotations:

```
local
  $(GEN_ROOT)/gen-lib.mlb

  ann
    "nonexhaustiveBind ignore"
    "nonexhaustiveMatch ignore"
  in
    foo.gen.sml
  end
in
  signature FOO
  structure Foo
end
```

Deliver a library

Standard ML libraries can be delivered via `.mlb` files. Authors of such libraries should strive to be mindful of the ways in which programmers may choose to compile their programs. For example, although the defaults for `sequenceNonUnit` and `warnUnused` are `ignore` and `false`, periodically compiling with these annotations defaulted to `warn` and `true` can help uncover likely bugs. However, a programmer is unlikely to be interested in unused modules from an imported library, and the behavior of `sequenceNonUnit error` may be incompatible with some libraries. Hence, a library author may choose to deliver a library as follows:

```
ann
  "nonexhaustiveBind warn" "nonexhaustiveMatch warn"
  "redundantBind warn" "redundantMatch warn"
  "sequenceNonUnit warn"
  "warnUnused true" "forceUsed"
in
  local
    file1.sml
    ...
    filen.sml
  in
    functor F1
    ...
    signature S1
    ...
    structure SN
    ...
  end
end
```

The annotations `nonexhaustiveBind warn`, `redundantBind warn`, `nonexhaustiveMatch warn`, `redundantMatch warn`, and `sequenceNonUnit warn` have the obvious effect on elaboration. The annotations `warnUnused true` and `forceUsed` work in conjunction — warning on any identifiers that do not contribute to the exported modules, and preventing warnings on exported modules that are not used in the remainder of the program. Many of the available libraries are delivered with these annotations.

MLBasisAnnotations

ML Basis annotations control options that affect the elaboration of SML source files. Conceptually, a basis file is elaborated in a default annotation environment (just as it is elaborated in an empty basis). The declaration `ann "ann" in basdec end` merges the annotation *ann* with the "current" annotation environment for the elaboration of *basdec*. To allow for future expansion, "*ann*" is lexed as a single SML string constant. To conveniently specify multiple annotations, the following derived form is provided:

```
ann "ann" ("ann" )+ in basdec end ⇒ ann "ann" in ann ("ann")+ in basdec end end
```

Here are the available annotations. In the explanation below, for annotations that take an argument, the first value listed is the default.

- `allowFFI {false|true}`

  If `true`, allow `_address`, `_export`, `_import`, and `_symbol` expressions to appear in source files. See ForeignFunctionInterface.

- `allowSuccessorML {false|true}`

  Allow or disallow all of the SuccessorML features. This is a proxy for all of the following annotations.

  - `allowDoDecls {false|true}`
    If `true`, allow a `do exp` declaration form.
  - `allowExtendedConsts {false|true}`
    Allow or disallow all of the extended constants features. This is a proxy for all of the following annotations.
    * `allowExtendedNumConsts {false|true}`
      If `true`, allow extended numeric constants.
    * `allowExtendedTextConsts {false|true}`
      If `true`, allow extended text constants.
  - `allowLineComments {false|true}`
    If `true`, allow line comments beginning with the token `(*)`.
  - `allowOptBar {false|true}`
    If `true`, allow a bar to appear before the first match rule of a `case`, `fn`, or `handle` expression, allow a bar to appear before the first function-value binding of a `fun` declaration, and allow a bar to appear before the first constructor binding or description of a `datatype` declaration or specification.
  - `allowOptSemicolon {false|true}`
    If `true`, allows a semicolon to appear after the last expression in a sequence expression or `let` body.
  - `allowOrPats {false|true}`
    If `true`, allows disjunctive (a.k.a., "or") patterns of the form `pat | pat`.
  - `allowRecordPunExps {false|true}`
    If `true`, allows record punning expressions.
  - `allowSigWithtype {false|true}`
    If `true`, allows `withtype` to modify a `datatype` specification in a signature.
  - `allowVectorExpsAndPats {false|true}`
    Allow or disallow vector expressions and vector patterns. This is a proxy for all of the following annotations.
    * `allowVectorExps {false|true}`
      If `true`, allow vector expressions.
    * `allowVectorPats {false|true}`
      If `true`, allow vector patterns.

- `forceUsed`

  Force all identifiers in the basis denoted by the body of the `ann` to be considered used; use in conjunction with `warnUnused true`.

- `nonexhaustiveBind {warn|error|ignore}`

  If `error` or `warn`, report nonexhaustive patterns in `val` declarations (i.e., pattern-match failures that raise the `Bind` exception). An error will abort a compile, while a warning will not.

- `nonexhaustiveExnBind {default|ignore}`

  If `ignore`, suppress errors and warnings about nonexhaustive matches in `val` declarations that arise solely from unmatched exceptions. If `default`, follow the behavior of `nonexhaustiveBind`.

- `nonexhaustiveExnMatch {default|ignore}`

  If `ignore`, suppress errors and warnings about nonexhaustive matches in `fn` expressions, `case` expressions, and `fun` declarations that arise solely from unmatched exceptions. If `default`, follow the behavior of `nonexhaustiveMatch`.

- `nonexhaustiveExnRaise {ignore|default}`

  If `ignore`, suppress errors and warnings about nonexhaustive matches in `handle` expressions that arise solely from unmatched exceptions. If `default`, follow the behavior of `nonexhaustiveRaise`.

- `nonexhaustiveMatch {warn|error|ignore}`

  If `error` or `warn`, report nonexhaustive patterns in `fn` expressions, `case` expressions, and `fun` declarations (i.e., pattern-match failures that raise the `Match` exception). An error will abort a compile, while a warning will not.

- `nonexhaustiveRaise {ignore|warn|error}`

  If `error` or `warn`, report nonexhaustive patterns in `handle` expressions (i.e., pattern-match failures that implicitly (re)raise the unmatched exception). An error will abort a compile, while a warning will not.

- `redundantBind {warn|error|ignore}`

  If `error` or `warn`, report redundant patterns in `val` declarations. An error will abort a compile, while a warning will not.

- `redundantMatch {warn|error|ignore}`

  If `error` or `warn`, report redundant patterns in `fn` expressions, `case` expressions, and `fun` declarations. An error will abort a compile, while a warning will not.

- `redundantRaise {warn|error|ignore}`

  If `error` or `warn`, report redundant patterns in `handle` expressions. An error will abort a compile, while a warning will not.

- `resolveScope {strdec|dec|topdec|program}`

  Used to control the scope at which overload constraints are resolved to default types (if not otherwise resolved by type inference) and the scope at which unresolved flexible record constraints are reported.

  The syntactic-class argument means to perform resolution checks at the smallest enclosing syntactic form of the given class. The default behavior is to resolve at the smallest enclosing *strdec* (which is equivalent to the largest enclosing *dec*). Other useful behaviors are to resolve at the smallest enclosing *topdec* (which is equivalent to the largest enclosing *strdec*) and at the smallest enclosing *program* (which corresponds to a single `.sml` file and does not correspond to the whole `.mlb` program).

- `sequenceNonUnit {ignore|error|warn}`

  If `error` or `warn`, report when `e1` is not of type `unit` in the sequence expression `(e1;e2)`. This can be helpful in detecting curried applications that are mistakenly not fully applied. To silence spurious messages, you can use `ignore e1`.

- `valrecConstr {warn|error|ignore}`

  If `error` or `warn`, report when a `val rec` (or `fun`) declaration redefines an identifier that previously had constructor status. An error will abort a compile, while a warning will not.

- `warnUnused {false|true}`

  Report unused identifiers.

Next Steps

- MLBasisAnnotationExamples
- WarnUnusedAnomalies

MLBasisAvailableLibraries

MLton comes with the following ML Basis files available.

- `$(SML_LIB)/basis/basis.mlb`
  The Basis Library.
- `$(SML_LIB)/basis/basis-1997.mlb`
  The (deprecated) 1997 version of the Basis Library.
- `$(SML_LIB)/basis/mlton.mlb`
  The MLton structure and signatures.
- `$(SML_LIB)/basis/c-types.mlb`
  Various structure aliases useful as ForeignFunctionInterfaceTypes.
- `$(SML_LIB)/basis/unsafe.mlb`
  The Unsafe structure and signature.
- `$(SML_LIB)/basis/sml-nj.mlb`
  The SMLofNJ structure and signature.
- `$(SML_LIB)/mlyacc-lib/mlyacc-lib.mlb`
  Modules used by parsers built with MLYacc.
- `$(SML_LIB)/cml/cml.mlb`
  ConcurrentML, a library for message-passing concurrency.
- `$(SML_LIB)/mlnlffi-lib/mlnlffi-lib.mlb`
  ML-NLFFI, a library for foreign function interfaces.
- `$(SML_LIB)/mlrisc-lib/...`
  MLRISCLibrary, a library for retargetable and optimizing compiler back ends.
- `$(SML_LIB)/smlnj-lib/...`
  SMLNJLibrary, a collection of libraries distributed with SML/NJ.
- `$(SML_LIB)/ckit-lib/ckit-lib.mlb`
  CKitLibrary, a library for C source code.
- `$(SML_LIB)/mllpt-lib/mllpt-lib.mlb`
  MLLPTLibrary, a support library for the MLULex scanner generator and the MLAntlr parser generator.

Basis fragments

There are a number of specialized ML Basis files for importing fragments of the Basis Library that can not be expressed within SML.

- `$(SML_LIB)/basis/pervasive-types.mlb`
  The top-level types and constructors of the Basis Library.
- `$(SML_LIB)/basis/pervasive-exns.mlb`
  The top-level exception constructors of the Basis Library.

- `$(SML_LIB)/basis/pervasive-vals.mlb`

  The top-level values of the Basis Library, without infix status.

- `$(SML_LIB)/basis/overloads.mlb`

  The top-level overloaded values of the Basis Library, without infix status.

- `$(SML_LIB)/basis/equal.mlb`

  The polymorphic equality = and inequality <> values, without infix status.

- `$(SML_LIB)/basis/infixes.mlb`

  The infix declarations of the Basis Library.

- `$(SML_LIB)/basis/pervasive.mlb`

  The entire top-level value and type environment of the Basis Library, with infix status. This is the same as importing the above six MLB files.

MLBasisExamples

Here are some example uses of ML Basis files.

Complete program

Suppose your complete program consists of the files `file1.sml`, ..., `filen.sml`, which depend upon libraries `lib1.mlb`, ..., `libm.mlb`.

```
(* import libraries *)
lib1.mlb
...
libm.mlb

(* program files *)
file1.sml
...
filen.sml
```

The bases denoted by `lib1.mlb`, ..., `libm.mlb` are merged (bindings of names in later bases take precedence over bindings of the same name in earlier bases), producing a basis in which `file1.sml`, ..., `filen.sml` are elaborated, adding additional bindings to the basis.

Export filter

Suppose you only want to export certain structures, signatures, and functors from a collection of files.

```
local
  file1.sml
  ...
  filen.sml
in
  (* export filter here *)
  functor F
  structure S
end
```

While `file1.sml`, ..., `filen.sml` may declare top-level identifiers in addition to `F` and `S`, such names are not accessible to programs and libraries that import this `.mlb`.

Export filter with renaming

Suppose you want an export filter, but want to rename one of the modules.

```
local
  file1.sml
  ...
  filen.sml
in
  (* export filter, with renaming, here *)
  functor F
  structure S' = S
end
```

Note that `functor F` is an abbreviation for `functor F =F`, which simply exports an identifier under the same name.

Import filter

Suppose you only want to import a functor F from one library and a structure S from another library.

```
local
  lib1.mlb
in
  (* import filter here *)
  functor F
end
local
  lib2.mlb
in
  (* import filter here *)
  structure S
end
file1.sml
...
filen.sml
```

Import filter with renaming

Suppose you want to import a structure S from one library and another structure S from another library.

```
local
  lib1.mlb
in
  (* import filter, with renaming, here *)
  structure S1 = S
end
local
  lib2.mlb
in
  (* import filter, with renaming, here *)
  structure S2 = S
end
file1.sml
...
filen.sml
```

Full Basis

Since the Modules level of SML is the natural means for organizing program and library components, MLB files provide convenient syntax for renaming Modules level identifiers (in fact, renaming of functor identifiers provides a mechanism that is not available in SML). However, please note that .mlb files elaborate to full bases including top-level types and values (including infix status), in addition to structures, signatures, and functors. For example, suppose you wished to extend the Basis Library with an ('a, 'b) either datatype corresponding to a disjoint sum; the type and some operations should be available at the top-level; additionally, a signature and structure provide the complete interface.

We could use the following files.

either-sigs.sml

```
signature EITHER_GLOBAL =
  sig
    datatype ('a, 'b) either = Left of 'a | Right of 'b
    val &  : ('a -> 'c) * ('b -> 'c) -> ('a, 'b) either -> 'c
    val && : ('a -> 'c) * ('b -> 'd) -> ('a, 'b) either -> ('c, 'd) either
  end
```

```
signature EITHER =
  sig
    include EITHER_GLOBAL
    val isLeft  : ('a, 'b) either -> bool
    val isRight : ('a, 'b) either -> bool
    ...
  end
```

either-strs.sml

```
structure Either : EITHER =
  struct
    datatype ('a, 'b) either = Left of 'a | Right of 'b
    fun f & g = fn x =>
      case x of Left z => f z | Right z => g z
    fun f && g = (Left o f) & (Right o g)
    fun isLeft x = ((fn _ => true) & (fn _ => false)) x
    fun isRight x = (not o isLeft) x
    ...
  end
structure EitherGlobal : EITHER_GLOBAL = Either
```

either-infixes.sml

```
infixr 3 & &&
```

either-open.sml

```
open EitherGlobal
```

either.mlb

```
either-infixes.sml
local
  (* import Basis Library *)
  $(SML_LIB)/basis/basis.mlb
  either-sigs.sml
  either-strs.sml
in
  signature EITHER
  structure Either
  either-open.sml
end
```

A client that imports `either.mlb` will have access to neither `EITHER_GLOBAL` nor `EitherGlobal`, but will have access to the type `either` and the values `&` and `&&` (with infix status) in the top-level environment. Note that `either-infixes.sml` is outside the scope of the local, because we want the infixes available in the implementation of the library and to clients of the library.

MLBasisPathMap

An ML Basis *path map* describes a map from ML Basis path variables (of the form `$(VAR)`) to file system paths. ML Basis path variables provide a flexible way to refer to libraries while allowing them to be moved without changing their clients.

The format of an `mlb-path-map` file is a sequence of lines; each line consists of two, white-space delimited tokens. The first token is a path variable `VAR` and the second token is the path to which the variable is mapped. The path may include path variables, which are recursively expanded.

The mapping from path variables to paths is initialized by the compiler. Additional path maps can be specified with `-mlb-path-map` and individual path variable mappings can be specified with `-mlb-path-var` (see CompileTimeOptions). Configuration files are processed from first to last and from top to bottom, later mappings take precedence over earlier mappings.

The compiler and system-wide configuration file makes the following path variables available.

MLB path variable	Description
`SML_LIB`	path to system-wide libraries, usually `/usr/lib/mlton/sml`
`TARGET_ARCH`	string representation of target architecture
`TARGET_OS`	string representation of target operating system
`DEFAULT_INT`	binding for default int, usually `int32`
`DEFAULT_WORD`	binding for default word, usually `word32`
`DEFAULT_REAL`	binding for default real, usually `real64`

MLBasisSyntaxAndSemantics

An ML Basis (MLB) file should have the `.mlb` suffix and should contain a basis declaration.

Syntax

A basis declaration (*basdec*) must be one of the following forms.

- `basis` *basid* = *basexp* (`and` *basid* = *basexp*)*
- `open` $basid_1$ ... $basid_n$
- `local` *basdec* `in` *basdec* `end`
- *basdec* [`;`] *basdec*
- `structure` *strid* [= *strid*] (`and` *strid*[= *strid*])*
- `signature` *sigid* [= *sigid*] (`and` *sigid* [= *sigid*])*
- `functor` *funid* [= *funid*] (`and` *funid* [= *funid*])*
- *path*`.sml`, *path*`.sig`, or *path*`.fun`
- *path*`.mlb`
- `ann` `"`*ann*`"` `in` *basdec* `end`

A basis expression (*basexp*) must be of one the following forms.

- `bas` *basdec* `end`
- *basid*
- `let` *basdec* `in` *basexp* `end`

Nested SML-style comments (enclosed with `(*` and `*)`) are ignored (but LineDirectives are recognized).

Paths can be relative or absolute. Relative paths are relative to the directory containing the MLB file. Paths may include path variables and are expanded according to a path map. Unquoted paths may include alpha-numeric characters and the symbols "-" and "_", along with the arc separator "/" and extension separator ".". More complicated paths, including paths with spaces, may be included by quoting the path with `"`. A quoted path is lexed as an SML string constant.

Annotations allow a library author to control options that affect the elaboration of SML source files.

Semantics

There is a formal semantics for ML Basis files in the style of the Definition. Here, we give an informal explanation.

An SML structure is a collection of types, values, and other structures. Similarly, a basis is a collection, but of more kinds of objects: types, values, structures, fixities, signatures, functors, and other bases.

A basis declaration denotes a basis. A structure, signature, or functor declaration denotes a basis containing the corresponding module. Sequencing of basis declarations merges bases, with later definitions taking precedence over earlier ones, just like sequencing of SML declarations. Local declarations provide name hiding, just like SML local declarations. A reference to an SML source file causes the file to be elaborated in the basis extant at the point of reference. A reference to an MLB file causes the basis denoted by that MLB file to be imported — the basis at the point of reference does *not* affect the imported basis.

Basis expressions and basis identifiers allow binding a basis to a name.

An MLB file is elaborated starting in an empty basis. Each MLB file is elaborated and evaluated only once, with the result being cached. Subsequent references use the cached value. Thus, any observable effects due to evaluation are not duplicated if the MLB file is referred to multiple times.

MLj

MLj is a Standard ML implementation that targets Java bytecode. It is no longer maintained. It has morphed into SML.NET.

Also see

- BentonEtAl98
- BentonKennedy99

MLKit

The ML Kit is a Standard ML implementation.

MLKit supports:

- SML'97
  - including most of the latest Basis Library specification,
- ML Basis files
  - and separate compilation,
- Region-Based Memory Management
  - and garbage collection,
- Multiple backends, including
  - native x86,
  - bytecode, and
  - JavaScript (see SMLtoJs).

At the time of writing, MLKit does not support:

- concurrent programming / threads,
- calling from C to SML.

MLLex

MLLex is a lexical analyzer generator for Standard ML modeled after the Lex lexical analyzer generator.

A version of MLLex, ported from the SML/NJ sources, is distributed with MLton.

Description

MLLex takes as input the lex language as defined in the ML-Lex manual, and outputs a lexical analyzer in SML.

Implementation

- `lexgen.sml`
- `main.sml`
- `call-main.sml`

Details and Notes

There are 3 main passes in the MLLex tool:

- Source parsing. In this pass, lex source program are parsed into internal representations. The core part of this pass is a hand-written lexer and an LL(1) parser. The output of this pass is a record of user code, rules (along with start states) and actions. (MLLex definitions are wiped off.)
- DFA construction. In this pass, a DFA is constructed by the algorithm of H. Yamada et. al.
- Output. In this pass, the generated DFA is written out as a transition table, along with a table-driven algorithm, to an SML file.

Also see

- `mllex.pdf`
- MLYacc
- AppelEtAl94
- Price09

MLLPTLibrary

The ML-LPT Library is a support library for the MLULex scanner generator and the MLAntlr parser generator. The ML-LPT Library is distributed with SML/NJ.

As of 20180119, MLton includes the ML-LPT Library synchronized with SML/NJ version 110.82.

Usage

- You can import the ML-LPT Library into an MLB file with:

MLB file	Description
`$(SML_LIB)/mllpt-lib/mllpt-lib.mlb`	

- If you are porting a project from SML/NJ's CompilationManager to MLton's ML Basis system using `cm2mlb`, note that the following map is included by default:

```
# MLLPT Library
$ml-lpt-lib.cm                          $(SML_LIB)/mllpt-lib
$ml-lpt-lib.cm/ml-lpt-lib.cm            $(SML_LIB)/mllpt-lib/mllpt-lib.mlb
```

  This will automatically convert a `$/mllpt-lib.cm` import in an input `.cm` file into a `$(SML_LIB)/mllpt-lib/mllpt-lib.mlb` import in the output `.mlb` file.

Details

Patch

- `ml-lpt.patch`

MLmon

An `mlmon.out` file records dynamic profiling counts.

File format

An `mlmon.out` file is a text file with a sequence of lines.

- The string "`MLton prof`".
- The string "`alloc`", "`count`", or "`time`", depending on the kind of profiling information, corresponding to the command-line argument supplied to `mlton -profile`.
- The string "`current`" or "`stack`" depending on whether profiling data was gathered for only the current function (the top of the stack) or for all functions on the stack. This corresponds to whether the executable was compiled with `-profile-stack false` or `-profile-stack true`.
- The magic number of the executable.
- The number of non-gc ticks, followed by a space, then the number of GC ticks.
- The number of (split) functions for which data is recorded.
- A line for each (split) function with counts. Each line contains an integer count of the number of ticks while the function was current. In addition, if stack data was gathered (`-profile-stack true`), then the line contains two additional tick counts:
  - the number of ticks while the function was on the stack.
  - the number of ticks while the function was on the stack and a GC was performed.
- The number of (master) functions for which data is recorded.
- A line for each (master) function with counts. The lines have the same format and meaning as with split-function counts.

MLNLFFI

ML-NLFFI is the no-longer-foreign-function interface library for SML.

As of 20050212, MLton has an initial port of ML-NLFFI from SML/NJ to MLton. All of the ML-NLFFI functionality is present.

Additionally, MLton has an initial port of the mlnlffigen tool from SML/NJ to MLton. Due to low-level details, the code generated by SML/NJ's `ml-nlffigen` is not compatible with MLton, and vice-versa. However, the generated code has the same interface, so portable client code can be written. MLton's `mlnlffigen` does not currently support C functions with `struct` or `union` arguments.

Usage

- You can import the ML-NLFFI Library into an MLB file with

MLB file	Description
`$(SML_LIB)/mlnlffi-lib/mlnlffi-lib.mlb`	

- If you are porting a project from SML/NJ's CompilationManager to MLton's ML Basis system using `cm2mlb`, note that the following maps are included by default:

```
# MLNLFFI Library
$c                                        $(SML_LIB)/mlnlffi-lib
$c/c.cm                                   $(SML_LIB)/mlnlffi-lib/mlnlffi-lib.mlb
```

  This will automatically convert a `$/c.cm` import in an input `.cm` file into a `$(SML_LIB)/mlnlffi-lib/mlnlffi-lib.mlb` import in the output `.mlb` file.

Also see

- Blume01
- MLNLFFIImplementation
- MLNLFFIGen

MLNLFFIGen

mlnlffigen generates a MLNLFFI binding from a collection of .c files. It is based on the CKitLibrary, which is primarily designed to handle standardized C and thus does not understand many (any?) compiler extensions; however, it attempts to recover from errors when seeing unrecognized definitions.

In order to work around common gcc extensions, it may be useful to add -cppopt options to the command line; for example -cppopt '-D__extension__' may be occasionally useful. Fortunately, most portable libraries largely avoid the use of these types of extensions in header files.

mlnlffigen will normally not generate bindings for #included files; see -match and -allSU if this is desirable.

MLNLFFIImplementation

MLton's implementation(s) of the MLNLFFI library differs from the SML/NJ implementation in two important ways:

- MLton cannot utilize the `Unsafe.cast` "cheat" described in Section 3.7 of Blume01. (MLton's representation of closures and aggressive representation optimizations make an `Unsafe.cast` even more "unsafe" than in other implementations.)

  We have considered two solutions:

  – One solution is to utilize an additional type parameter (as described in Section 3.7 of Blume01):

    ```
    signature C = sig
        type ('t, 'f, 'c) obj
        eqtype ('t, 'f, 'c) obj'
        ...
        type ('o, 'f) ptr
        eqtype ('o, 'f) ptr'
        ...
        type 'f fptr
        type 'f ptr'
        ...
        structure T : sig
            type ('t, 'f) typ
            ...
        end
    end
    ```

    The rule for `('t, 'f, 'c) obj`,`('t, 'f, 'c) ptr`, and also `('t, 'f) T.typ` is that whenever `F fptr` occurs within the instantiation of `'t`, then `'f` must be instantiated to `F`. In all other cases, `'f` will be instantiated to `unit`.

    (In the actual MLton implementation, an abstract type `naf` (not-a-function) is used instead of `unit`.)

    While this means that type-annotated programs may not type-check under both the SML/NJ implementation and the MLton implementation, this should not be a problem in practice. Tools, like `ml-nlffigen`, which are necessarily implementation dependent (in order to make calls through a C function pointer), may be easily extended to emit the additional type parameter. Client code which uses such generated glue-code (e.g., Section 1 of Blume01) need rarely write type-annotations, thanks to the magic of type inference.

  – The above implementation suffers from two disadvantages.

    First, it changes the MLNLFFI Library interface, meaning that the same program may not type-check under both the SML/NJ implementation and the MLton implementation (though, in light of type inference and the richer `MLRep` structure provided by MLton, this point is mostly moot).

    Second, it appears to unnecessarily duplicate type information. For example, an external C variable of type `int (* f[3])(int)` (that is, an array of three function pointers), would be represented by the SML type `(((sint -> sint) fptr, dec dg3) arr, sint -> sint, rw) obj`. One might well ask why the `'f` instantiation (`sint -> sint` in this case) cannot be *extracted* from the `'t` instantiation (`((sint -> sint) fptr, dec dg3) arr` in this case), obviating the need for a separate *function-type* type argument. There are a number of components to an complete answer to this question. Foremost is the fact that Standard ML supports neither (general) type-level functions nor intensional polymorphism.

    A more direct answer for MLNLFFI is that in the SML/NJ implemention, the definition of the types `('t, 'c) obj` and `('t, 'c) ptr` are made in such a way that the type variables `'t` and `'c` are phantom (not contributing to the run-time representation of an `('t, 'c) obj` or `('t, 'c) ptr` value), despite the fact that the types `((sint -> sint) fptr, rw) ptr` and `((double -> double) fptr, rw) ptr` necessarily carry distinct (and type incompatible) run-time (C-)type information (RTTI), corresponding to the different calling conventions of the two C functions. The `Unsafe.cast` "cheat" overcomes the type incompatibility without introducing a new type variable (as in the first solution above).

    Hence, the reason that *function-type* type cannot be extracted from the `'t` type variable instantiation is that the type of the representation of RTTI doesn't even *see* the (phantom) `'t` type variable. The solution which presents itself is to give up on the phantomness of the `'t` type variable, making it available to the representation of RTTI.

This is not without some small drawbacks. Because many of the types used to instantiate `'t` carry more structure than is strictly necessary for `'t`'s RTTI, it is sometimes necessary to wrap and unwrap RTTI to accommodate the additional structure. (In the other implementations, the corresponding operations can pass along the RTTI unchanged.) However, these coercions contribute minuscule overhead; in fact, in a majority of cases, MLton's optimizations will completely eliminate the RTTI from the final program.

The implementation distributed with MLton uses the second solution.

Bonus question: Why can't one use a universal type to eliminate the use of `Unsafe.cast`?

– Answer: ???

- MLton (in both of the above implementations) provides a richer `MLRep` structure, utilizing `Int`*<N>* and `Word`*<N>* structures.

```
structure MLRep = struct
    structure Char =
       struct
          structure Signed = Int8
          structure Unsigned = Word8
          (* word-style bit-operations on integers... *)
          structure <:SignedBitops:> = IntBitOps(structure I = Signed
                                                 structure W = Unsigned)
       end
    structure Short =
       struct
          structure Signed = Int16
          structure Unsigned = Word16
          (* word-style bit-operations on integers... *)
          structure <:SignedBitops:> = IntBitOps(structure I = Signed
                                                 structure W = Unsigned)
       end
    structure Int =
       struct
          structure Signed = Int32
          structure Unsigned = Word32
          (* word-style bit-operations on integers... *)
          structure <:SignedBitops:> = IntBitOps(structure I = Signed
                                                 structure W = Unsigned)
       end
    structure Long =
       struct
          structure Signed = Int32
          structure Unsigned = Word32
          (* word-style bit-operations on integers... *)
          structure <:SignedBitops:> = IntBitOps(structure I = Signed
                                                 structure W = Unsigned)
       end
    structure <:LongLong:> =
       struct
          structure Signed = Int64
          structure Unsigned = Word64
          (* word-style bit-operations on integers... *)
          structure <:SignedBitops:> = IntBitOps(structure I = Signed
                                                 structure W = Unsigned)
       end
    structure Float = Real32
    structure Double = Real64
end
```

This would appear to be a better interface, even when an implementation must choose `Int32` and `Word32` as the representation for smaller C-types.

MLRISCLibrary

The MLRISC Library is a framework for retargetable and optimizing compiler back ends. The MLRISC Library is distributed with SML/NJ. Due to differences between SML/NJ and MLton, this library will not work out-of-the box with MLton.

As of 20180119, MLton includes a port of the MLRISC Library synchronized with SML/NJ version 110.82.

Usage

- You can import a sub-library of the MLRISC Library into an MLB file with:

MLB file	Description
$(SML_LIB)/mlrisc-lib/mlb/ALPHA.mlb	The ALPHA backend
$(SML_LIB)/mlrisc-lib/mlb/AMD64.mlb	The AMD64 backend
$(SML_LIB)/mlrisc-lib/mlb/AMD64-Peephole.mlb	The AMD64 peephole optimizer
$(SML_LIB)/mlrisc-lib/mlb/CCall.mlb	
$(SML_LIB)/mlrisc-lib/mlb/CCall-sparc.mlb	
$(SML_LIB)/mlrisc-lib/mlb/CCall-x86-64.mlb	
$(SML_LIB)/mlrisc-lib/mlb/CCall-x86.mlb	
$(SML_LIB)/mlrisc-lib/mlb/Control.mlb	
$(SML_LIB)/mlrisc-lib/mlb/Graphs.mlb	
$(SML_LIB)/mlrisc-lib/mlb/HPPA.mlb	The HPPA backend
$(SML_LIB)/mlrisc-lib/mlb/IA32.mlb	The IA32 backend
$(SML_LIB)/mlrisc-lib/mlb/IA32-Peephole.mlb	The IA32 peephole optimizer
$(SML_LIB)/mlrisc-lib/mlb/Lib.mlb	
$(SML_LIB)/mlrisc-lib/mlb/MLRISC.mlb	
$(SML_LIB)/mlrisc-lib/mlb/MLTREE.mlb	
$(SML_LIB)/mlrisc-lib/mlb/Peephole.mlb	
$(SML_LIB)/mlrisc-lib/mlb/PPC.mlb	The PPC backend
$(SML_LIB)/mlrisc-lib/mlb/RA.mlb	
$(SML_LIB)/mlrisc-lib/mlb/SPARC.mlb	The Sparc backend
$(SML_LIB)/mlrisc-lib/mlb/StagedAlloc.mlb	
$(SML_LIB)/mlrisc-lib/mlb/Visual.mlb	

- If you are porting a project from SML/NJ's CompilationManager to MLton's ML Basis system using `cm2mlb`, note that the following map is included by default:

```
# MLRISC Library
$SMLNJ-MLRISC                           $(SML_LIB)/mlrisc-lib/mlb
```

  This will automatically convert a `$SMLNJ-MLRISC/MLRISC.cm` import in an input `.cm` file into a `$(SML_LIB)/mlrisc-lib/mlb/MLRISC.mlb` import in the output `.mlb` file.

Details

The following changes were made to the MLRISC Library, in addition to deriving the `.mlb` files from the `.cm` files:

- eliminate sequential `withtype` expansions: Most could be rewritten as a sequence of type definitions and datatype definitions.
- eliminate higher-order functors: Every higher-order functor definition and application could be uncurried in the obvious way.

- eliminate `where <str> =<str>`: Quite painful to expand out all the flexible types in the respective structures. Furthermore, many of the implied type equalities aren't needed, but it's too hard to pick out the right ones.
- `library/array-noneq.sml` (added, not exported): Implements `signature ARRAY_NONEQ`, similar to `signature ARRAY` from the Basis Library, but replacing the latter's `eqtype 'a array ='a array` and `type 'a vector = 'a Vector.vector` with `type 'a array` and `type 'a vector`. Thus, array-like containers may match `ARRAY_NONEQ`, whereas only the pervasive `'a array` container may math `ARRAY`. (SML/NJ's implementation of `signature ARRAY` omits the type realizations.)
- `library/dynamic-array.sml` and `library/hash-array.sml` (modifed): Replace `include ARRAY` with `include ARRAY_NONEQ`; see above.

Patch

- `MLRISC.patch`

MLtonArray

```
signature MLTON_ARRAY =
   sig
      val unfoldi: int * 'b * (int * 'b -> 'a * 'b) -> 'a array * 'b
   end
```

- `unfoldi (n, b, f)`

  constructs an array a of length `n`, whose elements a_i are determined by the equations $b_0 = b$ and $(a_i, b_{i+1}) = f(i, b_i)$.

MLtonBinIO

```
signature MLTON_BIN_IO = MLTON_IO
```

See MLtonIO.

MLtonCont

```
signature MLTON_CONT =
   sig
      type 'a t

      val callcc: ('a t -> 'a) -> 'a
      val isolate: ('a -> unit) -> 'a t
      val prepend: 'a t * ('b -> 'a) -> 'b t
      val throw: 'a t * 'a -> 'b
      val throw': 'a t * (unit -> 'a) -> 'b
   end
```

- `type 'a t`

  the type of continuations that expect a value of type `'a`.

- `callcc f`

  applies `f` to the current continuation. This copies the entire stack; hence, `callcc` takes time proportional to the size of the current stack.

- `isolate f`

  creates a continuation that evaluates `f` in an empty context. This is a constant time operation, and yields a constant size stack.

- `prepend (k, f)`

  composes a function `f` with a continuation `k` to create a continuation that first does `f` and then does `k`. This is a constant time operation.

- `throw (k, v)`

  throws value `v` to continuation `k`. This copies the entire stack of `k`; hence, `throw` takes time proportional to the size of this stack.

- `throw' (k, th)`

  a generalization of throw that evaluates `th ()` in the context of `k`. Thus, for example, if `th ()` raises an exception or captures another continuation, it will see `k`, not the current continuation.

Also see

- MLtonContIsolateImplementation

MLtonContIsolateImplementation

As noted before, it is fairly easy to get the operational behavior of `isolate` with just `callcc` and `throw`, but establishing the right space behavior is trickier. Here, we show how to start from the obvious, but inefficient, implementation of `isolate` using only `callcc` and `throw`, and *derive* an equivalent, but more efficient, implementation of `isolate` using MLton's primitive stack capture and copy operations. This isn't a formal derivation, as we are not formally showing the equivalence of the programs (though I believe that they are all equivalent, modulo the space behavior).

Here is a direct implementation of isolate using only `callcc` and `throw`:

```
val isolate: ('a -> unit) -> 'a t =
  fn (f: 'a -> unit) =>
  callcc
  (fn k1 =>
   let
      val x = callcc (fn k2 => throw (k1, k2))
      val _ = (f x ; Exit.topLevelSuffix ())
              handle exn => MLtonExn.topLevelHandler exn
   in
      raise Fail "MLton.Cont.isolate: return from (wrapped) func"
   end)
```

We use the standard nested `callcc` trick to return a continuation that is ready to receive an argument, execute the isolated function, and exit the program. Both `Exit.topLevelSuffix` and `MLtonExn.topLevelHandler` will terminate the program.

Throwing to an isolated function will execute the function in a *semantically* empty context, in the sense that we never re-execute the *original* continuation of the call to isolate (i.e., the context that was in place at the time `isolate` was called). However, we assume that the compiler isn't able to recognize that the *original* continuation is unused; for example, while we (the programmer) know that `Exit.topLevelSuffix` and `MLtonExn.topLevelHandler` will terminate the program, the compiler may only see opaque calls to unknown foreign-functions. So, that original continuation (in its entirety) is part of the continuation returned by `isolate` and throwing to the continuation returned by `isolate` will execute `f x` (with the exit wrapper) in the context of that original continuation. Thus, the garbage collector will retain everything reachable from that original continuation during the evaluation of `f x`, even though it is *semantically* garbage.

Note that this space-leak is independent of the implementation of continuations (it arises in both MLton's stack copying implementation of continuations and would arise in SML/NJ's CPS-translation implementation); we are only assuming that the implementation can't *see* the program termination, and so must retain the original continuation (and anything reachable from it).

So, we need an *empty* continuation in which to execute `f x`. (No surprise there, as that is the written description of `isolate`.) To do this, we capture a top-level continuation and throw to that in order to execute `f x`:

```
local
val base: (unit -> unit) t =
  callcc
  (fn k1 =>
   let
      val th = callcc (fn k2 => throw (k1, k2))
      val _ = (th () ; Exit.topLevelSuffix ())
              handle exn => MLtonExn.topLevelHandler exn
   in
      raise Fail "MLton.Cont.isolate: return from (wrapped) func"
   end)
in
val isolate: ('a -> unit) -> 'a t =
  fn (f: 'a -> unit) =>
  callcc
  (fn k1 =>
   let
      val x = callcc (fn k2 => throw (k1, k2))
   in
      throw (base, fn () => f x)
```

```
   end)
end
```

We presume that `base` is evaluated *early* in the program. There is a subtlety here, because one needs to believe that this `base` continuation (which technically corresponds to the entire rest of the program evaluation) *works* as an empty context; in particular, we want it to be the case that executing `f x` in the `base` context retains less space than executing `f x` in the context in place at the call to `isolate` (as occurred in the previous implementation of `isolate`). This isn't particularly easy to believe if one takes a normal substitution-based operational semantics, because it seems that the context captured and bound to `base` is arbitrarily large. However, this context is mostly unevaluated code; the only heap-allocated values that are reachable from it are those that were evaluated before the evaluation of `base` (and used in the program after the evaluation of `base`). Assuming that `base` is evaluated *early* in the program, we conclude that there are few heap-allocated values reachable from its continuation. In contrast, the previous implementation of `isolate` could capture a context that has many heap-allocated values reachable from it (because we could evaluate `isolate f` *late* in the program and *deep* in a call stack), which would all remain reachable during the evaluation of `f x`. [We'll return to this point later, as it is taking a slightly MLton-esque view of the evaluation of a program, and may not apply as strongly to other implementations (e.g., SML/NJ).]

Now, once we throw to `base` and begin executing `f x`, only the heap-allocated values reachable from `f` and `x` and the few heap-allocated values reachable from `base` are retained by the garbage collector. So, it seems that `base` *works* as an empty context.

But, what about the continuation returned from `isolate f`? Note that the continuation returned by `isolate` is one that receives an argument `x` and then throws to `base` to evaluate `f x`. If we used a CPS-translation implementation (and assume sufficient beta-contractions to eliminate administrative redexes), then the original continuation passed to `isolate` (i.e., the continuation bound to `k1`) will not be free in the continuation returned by `isolate f`. Rather, the only free variables in the continuation returned by `isolate f` will be `base` and `f`, so the only heap-allocated values reachable from the continuation returned by `isolate f` will be those values reachable from `base` (assumed to be few) and those values reachable from `f` (necessary in order to execute `f` at some later point).

But, MLton doesn't use a CPS-translation implementation. Rather, at each call to `callcc` in the body of `isolate`, MLton will copy the current execution stack. Thus, `k2` (the continuation returned by `isolate f`) will include execution stack at the time of the call to `isolate f` — that is, it will include the *original* continuation of the call to `isolate f`. Thus, the heap-allocated values reachable from the continuation returned by `isolate f` will include those values reachable from `base`, those values reachable from `f`, and those values reachable from the original continuation of the call to `isolate f`. So, just holding on to the continuation returned by `isolate f` will retain all of the heap-allocated values live at the time `isolate f` was called. This leaks space, since, *semantically*, the continuation returned by `isolate f` only needs the heap-allocated values reachable from `f` (and `base`).

In practice, this probably isn't a significant issue. A common use of `isolate` is implement `abort`:

```
fun abort th = throw (isolate th, ())
```

The continuation returned by `isolate th` is dead immediately after being thrown to — the continuation isn't retained, so neither is the *semantic* garbage it would have retained.

But, it is easy enough to *move* onto the *empty* context `base` the capturing of the context that we want to be returned by `isolate f`:

```
local
val base: (unit -> unit) t =
  callcc
  (fn k1 =>
   let
      val th = callcc (fn k2 => throw (k1, k2))
      val _ = (th () ; Exit.topLevelSuffix ())
              handle exn => MLtonExn.topLevelHandler exn
   in
      raise Fail "MLton.Cont.isolate: return from (wrapped) func"
   end)
in
val isolate: ('a -> unit) -> 'a t =
  fn (f: 'a -> unit) =>
```

```
  callcc
  (fn k1 =>
   throw (base, fn () =>
          let
             val x = callcc (fn k2 => throw (k1, k2))
          in
             throw (base, fn () => f x)
          end))
end
```

This implementation now has the right space behavior; the continuation returned by `isolate f` will only retain the heap-allocated values reachable from `f` and from `base`. (Technically, the continuation will retain two copies of the stack that was in place at the time `base` was evaluated, but we are assuming that that stack small.)

One minor inefficiency of this implementation (given MLton's implementation of continuations) is that every `callcc` and `throw` entails copying a stack (albeit, some of them are small). We can avoid this in the evaluation of `base` by using a reference cell, because `base` is evaluated at the top-level:

```
local
val base: (unit -> unit) option t =
  let
     val baseRef: (unit -> unit) option t option ref = ref NONE
     val th = callcc (fn k => (base := SOME k; NONE))
  in
     case th of
        NONE => (case !baseRef of
                    NONE => raise Fail "MLton.Cont.isolate: missing base"
                  | SOME base => base)
      | SOME th => let
                      val _ = (th () ; Exit.topLevelSuffix ())
                              handle exn => MLtonExn.topLevelHandler exn
                   in
                      raise Fail "MLton.Cont.isolate: return from (wrapped)
                      func"
                   end
  end
in
val isolate: ('a -> unit) -> 'a t =
  fn (f: 'a -> unit) =>
  callcc
  (fn k1 =>
   throw (base, SOME (fn () =>
          let
             val x = callcc (fn k2 => throw (k1, k2))
          in
             throw (base, SOME (fn () => f x))
          end)))
end
```

Now, to evaluate `base`, we only copy the stack once (instead of 3 times). Because we don't have a dummy continuation around to initialize the reference cell, the reference cell holds a continuation `option`. To distinguish between the original evaluation of `base` (when we want to return the continuation) and the subsequent evaluations of `base` (when we want to evaluate a thunk), we capture a `(unit -> unit) option` continuation.

This seems to be as far as we can go without exploiting the concrete implementation of continuations in MLtonCont. Examining the implementation, we note that the type of continuations is given by

```
type 'a t = (unit -> 'a) -> unit
```

and the implementation of `throw` is given by

```
fun ('a, 'b) throw' (k: 'a t, v: unit -> 'a): 'b =
```

```
   (k v; raise Fail "MLton.Cont.throw': return from continuation")

fun ('a, 'b) throw (k: 'a t, v: 'a): 'b = throw' (k, fn () => v)
```

Suffice to say, a continuation is simply a function that accepts a thunk to yield the thrown value and the body of the function performs the actual throw. Using this knowledge, we can create a dummy continuation to initialize `baseRef` and greatly simplify the body of `isolate`:

```
local
val base: (unit -> unit) option t =
  let
     val baseRef: (unit -> unit) option t ref =
        ref (fn _ => raise Fail "MLton.Cont.isolate: missing base")
     val th = callcc (fn k => (baseRef := k; NONE))
  in
     case th of
        NONE => !baseRef
      | SOME th => let
                      val _ = (th () ; Exit.topLevelSuffix ())
                              handle exn => MLtonExn.topLevelHandler exn
                   in
                      raise Fail "MLton.Cont.isolate: return from (wrapped)
                      func"
                   end
  end
in
val isolate: ('a -> unit) -> 'a t =
  fn (f: 'a -> unit) =>
  fn (v: unit -> 'a) =>
  throw (base, SOME (f o v))
end
```

Note that this implementation of `isolate` makes it clear that the continuation returned by `isolate f` only retains the heap-allocated values reachable from `f` and `base`. It also retains only one copy of the stack that was in place at the time `base` was evaluated. Finally, it completely avoids making any copies of the stack that is in place at the time `isolate f` is evaluated; indeed, `isolate f` is a constant-time operation.

Next, suppose we limited ourselves to capturing `unit` continuations with `callcc`. We can't pass the thunk to be evaluated in the *empty* context directly, but we can use a reference cell.

```
local
val thRef: (unit -> unit) option ref = ref NONE
val base: unit t =
  let
     val baseRef: unit t ref =
        ref (fn _ => raise Fail "MLton.Cont.isolate: missing base")
     val () = callcc (fn k => baseRef := k)
  in
     case !thRef of
        NONE => !baseRef
      | SOME th =>
           let
              val _ = thRef := NONE
              val _ = (th () ; Exit.topLevelSuffix ())
                      handle exn => MLtonExn.topLevelHandler exn
           in
              raise Fail "MLton.Cont.isolate: return from (wrapped) func"
           end
  end
in
val isolate: ('a -> unit) -> 'a t =
  fn (f: 'a -> unit) =>
```

```
  fn (v: unit -> 'a) =>
  let
     val () = thRef := SOME (f o v)
  in
     throw (base, ())
  end
end
```

Note that it is important to set `thRef` to `NONE` before evaluating the thunk, so that the garbage collector doesn't retain all the heap-allocated values reachable from `f` and `v` during the evaluation of `f (v ())`. This is because `thRef` is still live during the evaluation of the thunk; in particular, it was allocated before the evaluation of `base` (and used after), and so is retained by continuation on which the thunk is evaluated.

This implementation can be easily adapted to use MLton's primitive stack copying operations.

```
local
val thRef: (unit -> unit) option ref = ref NONE
val base: Thread.preThread =
   let
      val () = Thread.copyCurrent ()
   in
      case !thRef of
         NONE => Thread.savedPre ()
       | SOME th =>
            let
               val () = thRef := NONE
               val _ = (th () ; Exit.topLevelSuffix ())
                       handle exn => MLtonExn.topLevelHandler exn
            in
               raise Fail "MLton.Cont.isolate: return from (wrapped) func"
            end
   end
in
val isolate: ('a -> unit) -> 'a t =
   fn (f: 'a -> unit) =>
   fn (v: unit -> 'a) =>
   let
      val () = thRef := SOME (f o v)
      val new = Thread.copy base
   in
      Thread.switchTo new
   end
end
```

In essence, `Thread.copyCurrent` copies the current execution stack and stores it in an implicit reference cell in the runtime system, which is fetchable with `Thread.savedPre`. When we are ready to throw to the isolated function, `Thread.copy` copies the saved execution stack (because the stack is modified in place during execution, we need to retain a pristine copy in case the isolated function itself throws to other isolated functions) and `Thread.switchTo` abandons the current execution stack, installing the newly copied execution stack.

The actual implementation of `MLton.Cont.isolate` simply adds some `Thread.atomicBegin` and `Thread.atomicEnd` commands, which effectively protect the global `thRef` and accommodate the fact that `Thread.switchTo` does an implicit `Thread.atomicEnd` (used for leaving a signal handler thread).

```
local
val thRef: (unit -> unit) option ref = ref NONE
val base: Thread.preThread =
   let
      val () = Thread.copyCurrent ()
   in
      case !thRef of
         NONE => Thread.savedPre ()
```

```
        | SOME th =>
             let
                val () = thRef := NONE
                val _ = MLton.atomicEnd (* Match 1 *)
                val _ = (th () ; Exit.topLevelSuffix ())
                        handle exn => MLtonExn.topLevelHandler exn
             in
                raise Fail "MLton.Cont.isolate: return from (wrapped) func"
             end
   end
in
val isolate: ('a -> unit) -> 'a t =
   fn (f: 'a -> unit) =>
   fn (v: unit -> 'a) =>
   let
      val _ = MLton.atomicBegin (* Match 1 *)
      val () = thRef := SOME (f o v)
      val new = Thread.copy base
      val _ = MLton.atomicBegin (* Match 2 *)
   in
      Thread.switchTo new (* Match 2 *)
   end
end
```

It is perhaps interesting to note that the above implementation was originally *derived* by specializing implementations of the MLtonThread `new`, `prepare`, and `switch` functions as if their only use was in the following implementation of `isolate`:

```
val isolate: ('a -> unit) -> 'a t =
   fn (f: 'a -> unit) =>
   fn (v: unit -> 'a) =>
   let
      val th = (f (v ()) ; Exit.topLevelSuffix ())
               handle exn => MLtonExn.topLevelHandler exn
      val t = MLton.Thread.prepare (MLton.Thread.new th, ())
   in
      MLton.Thread.switch (fn _ => t)
   end
```

It was pleasant to discover that it could equally well be *derived* starting from the `callcc` and `throw` implementation.

As a final comment, we noted that the degree to which the context of `base` could be considered *empty* (i.e., retaining few heap-allocated values) depended upon a slightly MLton-esque view. In particular, MLton does not heap allocate executable code. So, although the `base` context keeps a lot of unevaluated code *live*, such code is not heap allocated. In a system like SML/NJ, that does heap allocate executable code, one might want it to be the case that after throwing to an isolated function, the garbage collector retains only the code necessary to evaluate the function, and not any code that was necessary to evaluate the `base` context.

MLtonCross

The debian package MLton-Cross adds various targets to MLton. In combination with the emdebian project, this allows a debian system to compile SML files to other architectures.

Currently, these targets are supported:

- *Windows (MinGW)*
  - -target i586-mingw32msvc (mlton-target-i586-mingw32msvc)
  - -target amd64-mingw32msvc(mlton-target-amd64-mingw32msvc)
- *Linux (Debian)*
  - -target alpha-linux-gnu (mlton-target-alpha-linux-gnu)
  - -target arm-linux-gnueabi (mlton-target-arm-linux-gnueabi)
  - -target hppa-linux-gnu (mlton-target-hppa-linux-gnu)
  - -target i486-linux-gnu (mlton-target-i486-linux-gnu)
  - -target ia64-linux-gnu (mlton-target-ia64-linux-gnu)
  - -target mips-linux-gnu (mlton-target-mips-linux-gnu)
  - -target mipsel-linux-gnu (mlton-target-mipsel-linux-gnu)
  - -target powerpc-linux-gnu (mlton-target-powerpc-linux-gnu)
  - -target s390-linux-gnu (mlton-target-s390-linux-gnu)
  - -target sparc-linux-gnu (mlton-target-sparc-linux-gnu)
  - -target x86-64-linux-gnu (mlton-target-x86-64-linux-gnu)

Download

MLton-Cross is kept in-sync with the current MLton release.

- `mlton-cross_20100608.orig.tar.gz`

MLtonExn

```
signature MLTON_EXN =
   sig
      val addExnMessager: (exn -> string option) -> unit
      val history: exn -> string list

      val defaultTopLevelHandler: exn -> 'a
      val getTopLevelHandler: unit -> (exn -> unit)
      val setTopLevelHandler: (exn -> unit) -> unit
      val topLevelHandler: exn -> 'a
   end
```

- `addExnMessager f`

  adds `f` as a pretty-printer to be used by `General.exnMessage` for converting exceptions to strings. Messagers are tried in order from most recently added to least recently added.

- `history e`

  returns call stack at the point that `e` was first raised. Each element of the list is a file position. The elements are in reverse chronological order, i.e. the function called last is at the front of the list.

  `history e` will return `[]` unless the program is compiled with `-const 'Exn.keepHistory true'`.

- `defaultTopLevelHandler e`

  function that behaves as the default top level handler; that is, print out the unhandled exception message for `e` and exit.

- `getTopLevelHandler ()`

  get the top level handler.

- `setTopLevelHandler f`

  set the top level handler to the function `f`. The function `f` should not raise an exception or return normally.

- `topLevelHandler e`

  behaves as if the top level handler received the exception `e`.

MLtonFinalizable

```
signature MLTON_FINALIZABLE =
   sig
      type 'a t

      val addFinalizer: 'a t * ('a -> unit) -> unit
      val finalizeBefore: 'a t * 'b t -> unit
      val new: 'a -> 'a t
      val touch: 'a t -> unit
      val withValue: 'a t * ('a -> 'b) -> 'b
   end
```

A *finalizable* value is a container to which finalizers can be attached. A container holds a value, which is reachable as long as the container itself is reachable. A *finalizer* is a function that runs at some point after garbage collection determines that the container to which it is attached has become unreachable. A finalizer is treated like a signal handler, in that it runs asynchronously in a separate thread, with signals blocked, and will not interrupt a critical section (see MLtonThread).

- `addFinalizer (v, f)`

  adds `f` as a finalizer to `v`. This means that sometime after the last call to `withValue` on `v` completes and `v` becomes unreachable, `f` will be called with the value of `v`.

- `finalizeBefore (v1, v2)`

  ensures that `v1` will be finalized before `v2`. A cycle of values `v` = `v1`, ..., `vn` = `v` with `finalizeBefore (vi, vi+1)` will result in none of the `vi` being finalized.

- `new x`

  creates a new finalizable value, `v`, with value `x`. The finalizers of `v` will run sometime after the last call to `withValue` on `v` when the garbage collector determines that `v` is unreachable.

- `touch v`

  ensures that `v`'s finalizers will not run before the call to `touch`.

- `withValue (v, f)`

  returns the result of applying `f` to the value of `v` and ensures that `v`'s finalizers will not run before `f` completes. The call to `f` is a nontail call.

Example

Suppose that `finalizable.sml` contains the following:

```
signature CLIST =
   sig
      type t

      val cons: int * t -> t
      val sing: int -> t
      val sum: t -> int
   end

functor CList (structure F: MLTON_FINALIZABLE
               structure P: MLTON_POINTER
               structure Prim:
                  sig
                     val cons: int * P.t -> P.t
                     val free: P.t -> unit
                     val sing: int -> P.t
```

```
                     val sum: P.t -> int
                  end): CLIST =
   struct
      type t = P.t F.t

      fun cons (n: int, l: t) =
         F.withValue
         (l, fn w' =>
          let
             val c = F.new (Prim.cons (n, w'))
             val _ = F.addFinalizer (c, Prim.free)
             val _ = F.finalizeBefore (c, l)
          in
             c
          end)

      fun sing n =
         let
            val c = F.new (Prim.sing n)
            val _ = F.addFinalizer (c, Prim.free)
         in
            c
         end

      fun sum c = F.withValue (c, Prim.sum)
   end

functor Test (structure CList: CLIST
              structure MLton: sig
                                  structure GC:
                                     sig
                                        val collect: unit -> unit
                                     end
                               end) =
   struct
      fun f n =
         if n = 1
            then ()
         else
            let
               val a = Array.tabulate (n, fn i => i)
               val _ = Array.sub (a, 0) + Array.sub (a, 1)
            in
               f (n - 1)
            end

      val l = CList.sing 2
      val l = CList.cons (2,l)
      val l = CList.cons (2,l)
      val l = CList.cons (2,l)
      val l = CList.cons (2,l)
      val l = CList.cons (2,l)
      val l = CList.cons (2,l)
      val _ = MLton.GC.collect ()
      val _ = f 100
      val _ = print (concat ["listSum(l) = ",
                             Int.toString (CList.sum l),
                             "\n"])
      val _ = MLton.GC.collect ()
      val _ = f 100
   end
```

```
structure CList =
   CList (structure F = MLton.Finalizable
          structure P = MLton.Pointer
          structure Prim =
             struct
                val cons = _import "listCons": int * P.t -> P.t;
                val free = _import "listFree": P.t -> unit;
                val sing = _import "listSing": int -> P.t;
                val sum = _import "listSum": P.t -> int;
             end)

structure S = Test (structure CList = CList
                    structure MLton = MLton)
```

Suppose that `cons.c` contains the following.

```
#include <stdio.h>

typedef unsigned int uint;

typedef struct Cons {
        struct Cons *next;
        int value;
} *Cons;

Cons listCons (int n, Cons c) {
        Cons res;

        res = (Cons) malloc (sizeof(*res));
        fprintf (stderr, "0x%08x = listCons (%d)\n", (uint)res, n);
        res->next = c;
        res->value = n;
        return res;
}

Cons listSing (int n) {
        Cons res;

        res = (Cons) malloc (sizeof(*res));
        fprintf (stderr, "0x%08x = listSing (%d)\n", (uint)res, n);
        res->next = NULL;
        res->value = n;
        return res;
}

void listFree (Cons p) {
        fprintf (stderr, "listFree (0x%08x)\n", (uint)p);
        free (p);
}

int listSum (Cons c) {
        int res;

        fprintf (stderr, "listSum\n");
        res = 0;
        for (; c != NULL; c = c->next)
                res += c->value;
        return res;
}
```

We can compile these to create an executable with

```
% mlton -default-ann 'allowFFI true' finalizable.sml cons.c
```

Running this executable will create output like the following.

```
% finalizable
0x08072890 = listSing (2)
0x080728a0 = listCons (2)
0x080728b0 = listCons (2)
0x080728c0 = listCons (2)
0x080728d0 = listCons (2)
0x080728e0 = listCons (2)
0x080728f0 = listCons (2)
listSum
listSum(l) = 14
listFree (0x080728f0)
listFree (0x080728e0)
listFree (0x080728d0)
listFree (0x080728c0)
listFree (0x080728b0)
listFree (0x080728a0)
listFree (0x08072890)
```

Synchronous Finalizers

Finalizers in MLton are asynchronous. That is, they run at an unspecified time, interrupting the user program. It is also possible, and sometimes useful, to have synchronous finalizers, where the user program explicitly decides when to run enabled finalizers. We have considered this in MLton, and it seems possible, but there are some unresolved design issues. See the thread at

- http://www.mlton.org/pipermail/mlton/2004-September/016570.html

Also see

- Boehm03

MLtonGC

```
signature MLTON_GC =
   sig
      val collect: unit -> unit
      val pack: unit -> unit
      val setMessages: bool -> unit
      val setSummary: bool -> unit
      val unpack: unit -> unit
      structure Statistics :
         sig
            val bytesAllocated: unit -> IntInf.int
            val lastBytesLive: unit -> IntInf.int
            val numCopyingGCs: unit -> IntInf.int
            val numMarkCompactGCs: unit -> IntInf.int
            val numMinorGCs: unit -> IntInf.int
            val maxBytesLive: unit -> IntInf.int
         end
   end
```

- `collect ()`

  causes a garbage collection to occur.

- `pack ()`

  shrinks the heap as much as possible so that other processes can use available RAM.

- `setMessages b`

  controls whether diagnostic messages are printed at the beginning and end of each garbage collection. It is the same as the `gc-messages` runtime system option.

- `setSummary b`

  controls whether a summary of garbage collection statistics is printed upon termination of the program. It is the same as the `gc-summary` runtime system option.

- `unpack ()`

  resizes a packed heap to the size desired by the runtime.

- `Statistics.bytesAllocated ()`

  returns bytes allocated (as of the most recent garbage collection).

- `Statistics.lastBytesLive ()`

  returns bytes live (as of the most recent garbage collection).

- `Statistics.numCopyingGCs ()`

  returns number of (major) copying garbage collections performed (as of the most recent garbage collection).

- `Statistics.numMarkCompactGCs ()`

  returns number of (major) mark-compact garbage collections performed (as of the most recent garbage collection).

- `Statistics.numMinorGCs ()`

  returns number of minor garbage collections performed (as of the most recent garbage collection).

- `Statistics.maxBytesLive ()`

  returns maximum bytes live (as of the most recent garbage collection).

MLtonIntInf

```
signature MLTON_INT_INF =
   sig
      type t = IntInf.int

      val areSmall: t * t -> bool
      val gcd: t * t -> t
      val isSmall: t -> bool

      structure BigWord : WORD
      structure SmallInt : INTEGER
      datatype rep =
         Big of BigWord.word vector
       | Small of SmallInt.int
      val rep: t -> rep
      val fromRep : rep -> t option
   end
```

MLton represents an arbitrary precision integer either as an unboxed word with the bottom bit set to 1 and the top bits representing a small signed integer, or as a pointer to a vector of words, where the first word indicates the sign and the rest are the limbs of a GnuMP big integer.

- `type t`

  the same as type `IntInf.int`.

- `areSmall (a, b)`

  returns true iff both `a` and `b` are small.

- `gcd (a, b)`

  uses the GnuMP's fast gcd implementation.

- `isSmall a`

  returns true iff `a` is small.

- `BigWord :WORD`

  representation of a big `IntInf.int` as a vector of words; on 32-bit platforms, `BigWord` is likely to be equivalent to `Word32`, and on 64-bit platforms, `BigWord` is likely to be equivalent to `Word64`.

- `SmallInt :INTEGER`

  representation of a small `IntInf.int` as a signed integer; on 32-bit platforms, `SmallInt` is likely to be equivalent to `Int32`, and on 64-bit platforms, `SmallInt` is likely to be equivalent to `Int64`.

- `datatype rep`

  the underlying representation of an `IntInf.int`.

- `rep i`

  returns the underlying representation of `i`.

- `fromRep r`

  converts from the underlying representation back to an `IntInf.int`. If `fromRep r` is given anything besides the valid result of `rep i` for some `i`, this function call will return `NONE`.

MLtonIO

```
signature MLTON_IO =
   sig
      type instream
      type outstream

      val inFd: instream -> Posix.IO.file_desc
      val mkstemp: string -> string * outstream
      val mkstemps: {prefix: string, suffix: string} -> string * outstream
      val newIn: Posix.IO.file_desc * string -> instream
      val newOut: Posix.IO.file_desc * string -> outstream
      val outFd: outstream -> Posix.IO.file_desc
      val tempPrefix: string -> string
   end
```

- `inFd ins`

  returns the file descriptor corresponding to `ins`.

- `mkstemp s`

  like the C `mkstemp` function, generates and open a temporary file with prefix `s`.

- `mkstemps {prefix, suffix}`

  like `mkstemp`, except it has both a prefix and suffix.

- `newIn (fd, name)`

  creates a new instream from file descriptor `fd`, with `name` used in any `Io` exceptions later raised.

- `newOut (fd, name)`

  creates a new outstream from file descriptor `fd`, with `name` used in any `Io` exceptions later raised.

- `outFd out`

  returns the file descriptor corresponding to `out`.

- `tempPrefix s`

  adds a suitable system or user specific prefix (directory) for temp files.

MLtonItimer

```
signature MLTON_ITIMER =
   sig
      datatype t =
         Prof
       | Real
       | Virtual

      val set: t * {interval: Time.time, value: Time.time} -> unit
      val signal: t -> Posix.Signal.signal
   end
```

- `set (t, {interval, value})`

  sets the interval timer (using `setitimer`) specified by `t` to the given `interval` and `value`.

- `signal t`

  returns the signal corresponding to `t`.

MLtonLibraryProject

We have a MLton Library repository that is intended to collect libraries.

```
https://github.com/MLton/mltonlib
```

Libraries are kept in the `master` branch, and are grouped according to domain name, in the Java package style. For example, VesaKarvonen, who works at `ssh.com`, has been putting code at:

```
https://github.com/MLton/mltonlib/tree/master/com/ssh
```

StephenWeeks, owning `sweeks.com`, has been putting code at:

```
https://github.com/MLton/mltonlib/tree/master/com/sweeks
```

A "library" is a subdirectory of some such directory. For example, Stephen's basis-library replacement library is at

```
https://github.com/MLton/mltonlib/tree/master/com/sweeks/basic
```

We use "transparent per-library branching" to handle library versioning. Each library has an "unstable" subdirectory in which work happens. When one is happy with a library, one tags it by copying it to a stable version directory. Stable libraries are immutable — when one refers to a stable library, one always gets exactly the same code. No one has actually made a stable library yet, but, when I'm ready to tag my library, I was thinking that I would do something like copying

```
https://github.com/MLton/mltonlib/tree/master/com/sweeks/basic/unstable
```

to

```
https://github.com/MLton/mltonlib/tree/master/com/sweeks/basic/v1
```

So far, libraries in the MLton repository have been licensed under MLton's License. We haven't decided on whether that will be a requirement to be in the repository or not. For the sake of simplicity (a single license) and encouraging widest use of code, contributors are encouraged to use that license. But it may be too strict to require it.

If someone wants to contribute a new library to our repository or to work on an old one, they can make a pull request. If people want to work in their own repository, they can do so — that's the point of using domain names to prevent clashes. The idea is that a user should be able to bring library collections in from many different repositories without problems. And those libraries could even work with each other.

At some point we may want to settle on an MLBasisPathMap variable for the root of the library project. Or, we could reuse `SML_LIB`, and migrate what we currently keep there into the library infrastructure.

MLtonMonoArray

```
signature MLTON_MONO_ARRAY =
   sig
      type t
      type elem
      val fromPoly: elem array -> t
      val toPoly: t -> elem array
   end
```

- `type t`

  type of monomorphic array

- `type elem`

  type of array elements

- `fromPoly a`

  type cast a polymorphic array to its monomorphic counterpart; the argument and result arrays share the same identity

- `toPoly a`

  type cast a monomorphic array to its polymorphic counterpart; the argument and result arrays share the same identity

MLtonMonoVector

```
signature MLTON_MONO_VECTOR =
   sig
      type t
      type elem
      val fromPoly: elem vector -> t
      val toPoly: t -> elem vector
   end
```

- `type t`
  type of monomorphic vector
- `type elem`
  type of vector elements
- `fromPoly v`
  type cast a polymorphic vector to its monomorphic counterpart; in MLton, this is a constant-time operation
- `toPoly v`
  type cast a monomorphic vector to its polymorphic counterpart; in MLton, this is a constant-time operation

MLtonPlatform

```
signature MLTON_PLATFORM =
   sig
      structure Arch:
         sig
            datatype t = Alpha | AMD64 | ARM | ARM64 | HPPA | IA64 | m68k
                       | MIPS | PowerPC | PowerPC64 | S390 | Sparc | X86

            val fromString: string -> t option
            val host: t
            val toString: t -> string
         end

      structure OS:
         sig
            datatype t = AIX | Cygwin | Darwin | FreeBSD | Hurd | HPUX
                       | Linux | MinGW | NetBSD | OpenBSD | Solaris

            val fromString: string -> t option
            val host: t
            val toString: t -> string
         end
   end
```

- `datatype Arch.t`
  processor architectures
- `Arch.fromString a`
  converts from string to architecture. Case insensitive.
- `Arch.host`
  the architecture for which the program is compiled.
- `Arch.toString`
  string for architecture.
- `datatype OS.t`
  operating systems
- `OS.fromString`
  converts from string to operating system. Case insensitive.
- `OS.host`
  the operating system for which the program is compiled.
- `OS.toString`
  string for operating system.

MLtonPointer

```
signature MLTON_POINTER =
   sig
      eqtype t

      val add: t * word -> t
      val compare: t * t -> order
      val diff: t * t -> word
      val getInt8: t * int -> Int8.int
      val getInt16: t * int -> Int16.int
      val getInt32: t * int -> Int32.int
      val getInt64: t * int -> Int64.int
      val getPointer: t * int -> t
      val getReal32: t * int -> Real32.real
      val getReal64: t * int -> Real64.real
      val getWord8: t * int -> Word8.word
      val getWord16: t * int -> Word16.word
      val getWord32: t * int -> Word32.word
      val getWord64: t * int -> Word64.word
      val null: t
      val setInt8: t * int * Int8.int -> unit
      val setInt16: t * int * Int16.int -> unit
      val setInt32: t * int * Int32.int -> unit
      val setInt64: t * int * Int64.int -> unit
      val setPointer: t * int * t -> unit
      val setReal32: t * int * Real32.real -> unit
      val setReal64: t * int * Real64.real -> unit
      val setWord8: t * int * Word8.word -> unit
      val setWord16: t * int * Word16.word -> unit
      val setWord32: t * int * Word32.word -> unit
      val setWord64: t * int * Word64.word -> unit
      val sizeofPointer: word
      val sub: t * word -> t
   end
```

- `eqtype t`

  the type of pointers, i.e. machine addresses.

- `add (p, w)`

  returns the pointer `w` bytes after than `p`. Does not check for overflow.

- `compare (p1, p2)`

  compares the pointer `p1` to the pointer `p2` (as addresses).

- `diff (p1, p2)`

  returns the number of bytes `w` such that `add (p2, w) =p1`. Does not check for overflow.

- `get<X> (p, i)`

  returns the object stored at index i of the array of *X* objects pointed to by `p`. For example, `getWord32 (p, 7)` returns the 32-bit word stored 28 bytes beyond `p`.

- `null`

  the null pointer, i.e. 0.

- `set<X> (p, i, v)`

  assigns `v` to the object stored at index i of the array of *X* objects pointed to by `p`. For example, `setWord32 (p, 7, w)` stores the 32-bit word `w` at the address 28 bytes beyond `p`.

- `sizeofPointer`
  size, in bytes, of a pointer.
- `sub (p, w)`
  returns the pointer `w` bytes before `p`. Does not check for overflow.

MLtonProcEnv

```
signature MLTON_PROC_ENV =
   sig
      type gid

      val setenv: {name: string, value: string} -> unit
      val setgroups: gid list -> unit
   end
```

- `setenv {name, value}`

  like the C `setenv` function. Does not require `name` or `value` to be null terminated.

- `setgroups grps`

  like the C `setgroups` function.

MLtonProcess

```
signature MLTON_PROCESS =
   sig
      type pid

      val spawn: {args: string list, path: string} -> pid
      val spawne: {args: string list, env: string list, path: string} -> pid
      val spawnp: {args: string list, file: string} -> pid

      type ('stdin, 'stdout, 'stderr) t

      type input
      type output

      type none
      type chain
      type any

      exception MisuseOfForget
      exception DoublyRedirected

      structure Child:
        sig
          type ('use, 'dir) t

          val binIn: (BinIO.instream, input) t -> BinIO.instream
          val binOut: (BinIO.outstream, output) t -> BinIO.outstream
          val fd: (Posix.FileSys.file_desc, 'dir) t -> Posix.FileSys.file_desc
          val remember: (any, 'dir) t -> ('use, 'dir) t
          val textIn: (TextIO.instream, input) t -> TextIO.instream
          val textOut: (TextIO.outstream, output) t -> TextIO.outstream
        end

      structure Param:
        sig
          type ('use, 'dir) t

          val child: (chain, 'dir) Child.t -> (none, 'dir) t
          val fd: Posix.FileSys.file_desc -> (none, 'dir) t
          val file: string -> (none, 'dir) t
          val forget: ('use, 'dir) t -> (any, 'dir) t
          val null: (none, 'dir) t
          val pipe: ('use, 'dir) t
          val self: (none, 'dir) t
        end

      val create:
         {args: string list,
          env: string list option,
          path: string,
          stderr: ('stderr, output) Param.t,
          stdin: ('stdin, input) Param.t,
          stdout: ('stdout, output) Param.t}
         -> ('stdin, 'stdout, 'stderr) t
      val getStderr: ('stdin, 'stdout, 'stderr) t -> ('stderr, input) Child.t
      val getStdin:  ('stdin, 'stdout, 'stderr) t -> ('stdin, output) Child.t
      val getStdout: ('stdin, 'stdout, 'stderr) t -> ('stdout, input) Child.t
      val kill: ('stdin, 'stdout, 'stderr) t * Posix.Signal.signal -> unit
      val reap: ('stdin, 'stdout, 'stderr) t -> Posix.Process.exit_status
   end
```

Spawn

The spawn functions provide an alternative to the fork/exec idiom that is typically used to create a new process. On most platforms, the spawn functions are simple wrappers around fork/exec. However, under Windows, the spawn functions are primitive. All spawn functions return the process id of the spawned process. They differ in how the executable is found and the environment that it uses.

- `spawn {args, path}`

  starts a new process running the executable specified by `path` with the arguments `args`. Like `Posix.Process.exec`.

- `spawne {args, env, path}`

  starts a new process running the executable specified by `path` with the arguments `args` and environment `env`. Like `Posix.Process.exece`.

- `spawnp {args, file}`

  search the `PATH` environment variable for an executable named `file`, and start a new process running that executable with the arguments `args`. Like `Posix.Process.execp`.

Create

`MLton.Process.create` provides functionality similar to `Unix.executeInEnv`, but provides more control control over the input, output, and error streams. In addition, `create` works on all platforms, including Cygwin and MinGW (Windows) where `Posix.fork` is unavailable. For greatest portability programs should still use the standard `Unix.execute`, `Unix.executeInEnv`, and `OS.Process.system`.

The following types and sub-structures are used by the `create` function. They provide static type checking of correct stream usage.

Child

- `('use, 'dir) Child.t`

  This represents a handle to one of a child's standard streams. The `'dir` is viewed with respect to the parent. Thus a `('a, input) Child.t` handle means that the parent may input the output from the child.

- `Child.{bin,text}{In,Out} h`

  These functions take a handle and bind it to a stream of the named type. The type system will detect attempts to reverse the direction of a stream or to use the same stream in multiple, incompatible ways.

- `Child.fd h`

  This function behaves like the other `Child.*` functions; it opens a stream. However, it does not enforce that you read or write from the handle. If you use the descriptor in an inappropriate direction, the behavior is undefined. Furthermore, this function may potentially be unavailable on future MLton host platforms.

- `Child.remember h`

  This function takes a stream of use `any` and resets the use of the stream so that the stream may be used by `Child.*`. An `any` stream may have had use `none` or `'use` prior to calling `Param.forget`. If the stream was `none` and is used, `MisuseOfForget` is raised.

Param

- `('use, 'dir) Param.t`

  This is a handle to an input/output source and will be passed to the created child process. The `'dir` is relative to the child process. Input means that the child process will read from this stream.

- `Param.child h`

  Connect the stream of the new child process to the stream of a previously created child process. A single child stream should be connected to only one child process or else `DoublyRedirected` will be raised.

- `Param.fd fd`

  This creates a stream from the provided file descriptor which will be closed when `create` is called. This function may not be available on future MLton host platforms.

- `Param.forget h`

  This hides the type of the actual parameter as `any`. This is useful if you are implementing an application which conditionally attaches the child process to files or pipes. However, you must ensure that your use after `Child.remember` matches the original type.

- `Param.file s`

  Open the given file and connect it to the child process. Note that the file will be opened only when `create` is called. So any exceptions will be raised there and not by this function. If used for `input`, the file is opened read-only. If used for `output`, the file is opened read-write.

- `Param.null`

  In some situations, the child process should have its output discarded. The `null` param when passed as `stdout` or `stderr` does this. When used for `stdin`, the child process will either receive `EOF` or a failure condition if it attempts to read from `stdin`.

- `Param.pipe`

  This will connect the input/output of the child process to a pipe which the parent process holds. This may later form the input to one of the `Child.*` functions and/or the `Param.child` function.

- `Param.self`

  This will connect the input/output of the child process to the corresponding stream of the parent process.

Process

- `type ('stdin, 'stdout, 'stderr) t`

  represents a handle to a child process. The type arguments capture how the named stream of the child process may be used.

- `type any`

  bypasses the type system in situations where an application does not want the it to enforce correct usage. See `Child.remember` and `Param.forget`.

- `type chain`

  means that the child process's stream was connected via a pipe to the parent process. The parent process may pass this pipe in turn to another child, thus chaining them together.

- `type input, output`

  record the direction that a stream flows. They are used as a part of `Param.t` and `Child.t` and is detailed there.

- `type none`

  means that the child process's stream my not be used by the parent process. This happens when the child process is connected directly to some source.

  The types `BinIO.instream`, `BinIO.outstream`, `TextIO.instream`, `TextIO.outstream`, and `Posix.FileSys.file_desc` are also valid types with which to instantiate child streams.

- `exception MisuseOfForget`

  may be raised if `Child.remember` and `Param.forget` are used to bypass the normal type checking. This exception will only be raised in cases where the `forget` mechanism allows a misuse that would be impossible with the type-safe versions.

- `exception DoublyRedirected`

  raised if a stream connected to a child process is redirected to two separate child processes. It is safe, though bad style, to use the a `Child.t` with the same `Child.*` function repeatedly.

- `create {args, path, env, stderr, stdin, stdout}`

  starts a child process with the given command-line `args` (excluding the program name). `path` should be an absolute path to the executable run in the new child process; relative paths work, but are less robust. Optionally, the environment may be overridden with `env` where each string element has the form `"key=value"`. The `std*` options must be provided by the `Param.*` functions documented above.

  Processes which are `create`-d must be either `reap`-ed or `kill`-ed.

- `getStd{in,out,err} proc`

  gets a handle to the specified stream. These should be used by the `Child.*` functions. Failure to use a stream connected via pipe to a child process may result in runtime dead-lock and elicits a compiler warning.

- `kill (proc, sig)`

  terminates the child process immediately. The signal may or may not mean anything depending on the host platform. A good value is `Posix.Signal.term`.

- `reap proc`

  waits for the child process to terminate and return its exit status.

Important usage notes

When building an application with many pipes between child processes, it is important to ensure that there are no cycles in the undirected pipe graph. If this property is not maintained, deadlocks are a very serious potential bug which may only appear under difficult to reproduce conditions.

The danger lies in that most operating systems implement pipes with a fixed buffer size. If process A has two output pipes which process B reads, it can happen that process A blocks writing to pipe 2 because it is full while process B blocks reading from pipe 1 because it is empty. This same situation can happen with any undirected cycle formed between processes (vertexes) and pipes (undirected edges) in the graph.

It is possible to make this safe using low-level I/O primitives for polling. However, these primitives are not very portable and difficult to use properly. A far better approach is to make sure you never create a cycle in the first place.

For these reasons, the `Unix.executeInEnv` is a very dangerous function. Be careful when using it to ensure that the child process only operates on either `stdin` or `stdout`, but not both.

Example use of MLton.Process.create

The following example program launches the `ipconfig` utility, pipes its output through `grep`, and then reads the result back into the program.

```
open MLton.Process
val p =
        create {args = [ "/all" ],
                env = NONE,
                path = "C:\\WINDOWS\\system32\\ipconfig.exe",
                stderr = Param.self,
                stdin = Param.null,
                stdout = Param.pipe}
val q =
        create {args = [ "IP-Ad" ],
                env = NONE,
                path = "C:\\msys\\bin\\grep.exe",
                stderr = Param.self,
                stdin = Param.child (getStdout p),
```

```
                stdout = Param.pipe}
fun suck h =
        case TextIO.inputLine h of
                NONE => ()
                | SOME s => (print ("'" ^ s ^ "'\n"); suck h)

val () = suck (Child.textIn (getStdout q))
```

MLtonProfile

```
signature MLTON_PROFILE =
   sig
      structure Data:
         sig
            type t

            val equals: t * t -> bool
            val free: t -> unit
            val malloc: unit -> t
            val write: t * string -> unit
         end

      val isOn: bool
      val withData: Data.t * (unit -> 'a) -> 'a
   end
```

`MLton.Profile` provides Profiling control from within the program, allowing you to profile individual portions of your program. With `MLton.Profile`, you can create many units of profiling data (essentially, mappings from functions to counts) during a run of a program, switch between them while the program is running, and output multiple `mlmon.out` files.

- `isOn`

  a compile-time constant that is false only when compiling `-profile no`.

- `type Data.t`

  the type of a unit of profiling data. In order to most efficiently execute non-profiled programs, when compiling `-profile no` (the default), `Data.t` is equivalent to `unit ref`.

- `Data.equals (x, y)`

  returns true if the `x` and `y` are the same unit of profiling data.

- `Data.free x`

  frees the memory associated with the unit of profiling data `x`. It is an error to free the current unit of profiling data or to free a previously freed unit of profiling data. When compiling `-profile no`, `Data.free x` is a no-op.

- `Data.malloc ()`

  returns a new unit of profiling data. Each unit of profiling data is allocated from the process address space (but is *not* in the MLton heap) and consumes memory proportional to the number of source functions. When compiling `-profile no`, `Data.malloc ()` is equivalent to allocating a new `unit ref`.

- `write (x, f)`

  writes the accumulated ticks in the unit of profiling data `x` to file `f`. It is an error to write a previously freed unit of profiling data. When compiling `-profile no`, `write (x, f)` is a no-op. A profiled program will always write the current unit of profiling data at program exit to a file named `mlmon.out`.

- `withData (d, f)`

  runs `f` with `d` as the unit of profiling data, and returns the result of `f` after restoring the current unit of profiling data. When compiling `-profile no`, `withData (d, f)` is equivalent to `f ()`.

Example

Here is an example, taken from the `examples/profiling` directory, showing how to profile the executions of the `fib` and `tak` functions separately. Suppose that `fib-tak.sml` contains the following.

```
structure Profile = MLton.Profile

val fibData = Profile.Data.malloc ()
val takData = Profile.Data.malloc ()

fun wrap (f, d) x =
   Profile.withData (d, fn () => f x)

val rec fib =
   fn 0 => 0
    | 1 => 1
    | n => fib (n - 1) + fib (n - 2)
val fib = wrap (fib, fibData)

fun tak (x,y,z) =
   if not (y < x)
      then z
   else tak (tak (x - 1, y, z),
             tak (y - 1, z, x),
             tak (z - 1, x, y))
val tak = wrap (tak, takData)

val rec f =
   fn 0 => ()
    | n => (fib 38; f (n-1))
val _ = f 2

val rec g =
   fn 0 => ()
    | n => (tak (18,12,6); g (n-1))
val _ = g 500

fun done (data, file) =
   (Profile.Data.write (data, file)
    ; Profile.Data.free data)

val _ = done (fibData, "mlmon.fib.out")
val _ = done (takData, "mlmon.tak.out")
```

Compile and run the program.

```
% mlton -profile time fib-tak.sml
% ./fib-tak
```

Separately display the profiling data for `fib`

```
% mlprof fib-tak mlmon.fib.out
5.77 seconds of CPU time (0.00 seconds GC)
function   cur
--------- -----
fib       96.9%
<unknown>  3.1%
```

and for `tak`

```
% mlprof fib-tak mlmon.tak.out
0.68 seconds of CPU time (0.00 seconds GC)
function  cur
-------- ------
tak      100.0%
```

Combine the data for `fib` and `tak` by calling `mlprof` with multiple `mlmon.out` files.

```
% mlprof fib-tak mlmon.fib.out mlmon.tak.out mlmon.out
6.45 seconds of CPU time (0.00 seconds GC)
function   cur
--------- -----
fib       86.7%
tak       10.5%
<unknown>  2.8%
```

MLtonRandom

```
signature MLTON_RANDOM =
   sig
      val alphaNumChar: unit -> char
      val alphaNumString: int -> string
      val rand: unit -> word
      val seed: unit -> word option
      val srand: word -> unit
      val useed: unit -> word option
   end
```

- `alphaNumChar ()`

  returns a random alphanumeric character.

- `alphaNumString n`

  returns a string of length `n` of random alphanumeric characters.

- `rand ()`

  returns the next pseudo-random number.

- `seed ()`

  returns a random word from `/dev/random`. Useful as an arg to `srand`. If `/dev/random` can not be read from, `seed ()` returns `NONE`. A call to `seed` may block until enough random bits are available.

- `srand w`

  sets the seed used by `rand` to `w`.

- `useed ()`

  returns a random word from `/dev/urandom`. Useful as an arg to `srand`. If `/dev/urandom` can not be read from, `useed ()` returns `NONE`. A call to `useed` will never block — it will instead return lower quality random bits.

MLtonReal

```
signature MLTON_REAL =
   sig
      type t

      val fromWord: word -> t
      val fromLargeWord: LargeWord.word -> t
      val toWord: IEEEReal.rounding_mode -> t -> word
      val toLargeWord: IEEEReal.rounding_mode -> t -> LargeWord.word
   end
```

- `type t`

  the type of reals. For `MLton.LargeReal` this is `LargeReal.real`, for `MLton.Real` this is `Real.real`, for `MLton.Real32` this is `Real32.real`, for `MLton.Real64` this is `Real64.real`.

- `fromWord w`
- `fromLargeWord w`

  convert the word `w` to a real value. If the value of `w` is larger than (the appropriate) `REAL.maxFinite`, then infinity is returned. If `w` cannot be exactly represented as a real value, then the current rounding mode is used to determine the resulting value.

- `toWord mode r`
- `toLargeWord mode r`

  convert the argument `r` to a word type using the specified rounding mode. They raise `Overflow` if the result is not representable, in particular, if `r` is an infinity. They raise `Domain` if `r` is NaN.

- `MLton.Real32.castFromWord w`
- `MLton.Real64.castFromWord w`

  convert the argument `w` to a real type as a bit-wise cast.

- `MLton.Real32.castToWord r`
- `MLton.Real64.castToWord r`

  convert the argument `r` to a word type as a bit-wise cast.

MLtonRlimit

```
signature MLTON_RLIMIT =
   sig
      structure RLim : sig
                          type t
                          val castFromSysWord: SysWord.word -> t
                          val castToSysWord: t -> SysWord.word
                       end

      val infinity: RLim.t

      type t

      val coreFileSize: t         (* CORE    max core file size *)
      val cpuTime: t              (* CPU     CPU time in seconds *)
      val dataSize: t             (* DATA    max data size *)
      val fileSize: t             (* FSIZE   Maximum filesize *)
      val numFiles: t             (* NOFILE  max number of open files *)
      val lockedInMemorySize: t   (* MEMLOCK max locked address space *)
      val numProcesses: t         (* NPROC   max number of processes *)
      val residentSetSize: t      (* RSS     max resident set size *)
      val stackSize: t            (* STACK   max stack size *)
      val virtualMemorySize: t    (* AS      virtual memory limit *)

      val get: t -> {hard: rlim, soft: rlim}
      val set: t * {hard: rlim, soft: rlim} -> unit
   end
```

`MLton.Rlimit` provides a wrapper around the C `getrlimit` and `setrlimit` functions.

- `type Rlim.t`
  the type of resource limits.
- `infinity`
  indicates that a resource is unlimited.
- `type t`
  the types of resources that can be inspected and modified.
- `get r`
  returns the current hard and soft limits for resource `r`. May raise `OS.SysErr`.
- `set (r, {hard, soft})`
  sets the hard and soft limits for resource `r`. May raise `OS.SysErr`.

MLtonRusage

```
signature MLTON_RUSAGE =
   sig
      type t = {utime: Time.time, (* user time *)
                stime: Time.time} (* system time *)

      val measureGC: bool -> unit
      val rusage: unit -> {children: t, gc: t, self: t}
   end
```

- `type t`

  corresponds to a subset of the C `struct rusage`.

- `measureGC b`

  controls whether garbage collection time is separately measured during program execution. This affects the behavior of both `rusage` and `Timer.checkCPUTimes`, both of which will return gc times of zero with `measureGC false`. Garbage collection time is always measured when either `gc-messages` or `gc-summary` is given as a runtime system option.

- `rusage ()`

  corresponds to the C `getrusage` function. It returns the resource usage of the exited children, the garbage collector, and the process itself. The `self` component includes the usage of the `gc` component, regardless of whether `measureGC` is `true` or `false`. If `rusage` is used in a program, either directly, or indirectly via the `Timer` structure, then `measureGC true` is automatically called at the start of the program (it can still be disable by user code later).

MLtonSignal

```
signature MLTON_SIGNAL =
   sig
      type t = Posix.Signal.signal
      type signal = t

      structure Handler:
         sig
            type t

            val default: t
            val handler: (Thread.Runnable.t -> Thread.Runnable.t) -> t
            val ignore: t
            val isDefault: t -> bool
            val isIgnore: t -> bool
            val simple: (unit -> unit) -> t
         end

      structure Mask:
         sig
            type t

            val all: t
            val allBut: signal list -> t
            val block: t -> unit
            val getBlocked: unit -> t
            val isMember: t * signal -> bool
            val none: t
            val setBlocked: t -> unit
            val some: signal list -> t
            val unblock: t -> unit
         end

      val getHandler: t -> Handler.t
      val handled: unit -> Mask.t
      val prof: t
      val restart: bool ref
      val setHandler: t * Handler.t -> unit
      val suspend: Mask.t -> unit
      val vtalrm: t
   end
```

Signals handlers are functions from (runnable) threads to (runnable) threads. When a signal arrives, the corresponding signal handler is invoked, its argument being the thread that was interrupted by the signal. The signal handler runs asynchronously, in its own thread. The signal handler returns the thread that it would like to resume execution (this is often the thread that it was passed). It is an error for a signal handler to raise an exception that is not handled within the signal handler itself.

A signal handler is never invoked while the running thread is in a critical section (see MLtonThread). Invoking a signal handler implicitly enters a critical section and the normal return of a signal handler implicitly exits the critical section; hence, a signal handler is never interrupted by another signal handler.

- `type t`

  the type of signals.

- `type Handler.t`

  the type of signal handlers.

- `Handler.default`

  handles the signal with the default action.

- `Handler.handler f`
  returns a handler `h` such that when a signal `s` is handled by `h`, `f` will be passed the thread that was interrupted by `s` and should return the thread that will resume execution.
- `Handler.ignore`
  is a handler that will ignore the signal.
- `Handler.isDefault`
  returns true if the handler is the default handler.
- `Handler.isIgnore`
  returns true if the handler is the ignore handler.
- `Handler.simple f`
  returns a handler that executes `f ()` and does not switch threads.
- `type Mask.t`
  the type of signal masks, which are sets of blocked signals.
- `Mask.all`
  a mask of all signals.
- `Mask.allBut l`
  a mask of all signals except for those in `l`.
- `Mask.block m`
  blocks all signals in `m`.
- `Mask.getBlocked ()`
  gets the signal mask `m`, i.e. a signal is blocked if and only if it is in `m`.
- `Mask.isMember (m, s)`
  returns true if the signal `s` is in `m`.
- `Mask.none`
  a mask of no signals.
- `Mask.setBlocked m`
  sets the signal mask to `m`, i.e. a signal is blocked if and only if it is in `m`.
- `Mask.some l`
  a mask of the signals in `l`.
- `Mask.unblock m`
  unblocks all signals in `m`.
- `getHandler s`
  returns the current handler for signal `s`.
- `handled ()`
  returns the signal mask `m` corresponding to the currently handled signals; i.e., a signal is handled if and only if it is in `m`.
- `prof`
  `SIGPROF`, the profiling signal.
- `restart`
  dynamically determines the behavior of interrupted system calls; when `true`, interrupted system calls are restarted; when `false`, interrupted system calls raise `OS.SysError`.

- `setHandler (s, h)`
  sets the handler for signal `s` to `h`.
- `suspend m`
  temporarily sets the signal mask to `m` and suspends until an unmasked signal is received and handled, at which point `suspend` resets the mask and returns.
- `vtalrm`
  `SIGVTALRM`, the signal for virtual timers.

Interruptible System Calls

Signal handling interacts in a non-trivial way with those functions in the Basis Library that correspond directly to interruptible system calls (a subset of those functions that may raise `OS.SysError`). The desire is that these functions should have predictable semantics. The principal concerns are:

1. System calls that are interrupted by signals should, by default, be restarted; the alternative is to raise
   ```
   OS.SysError (Posix.Error.errorMsg Posix.Error.intr,
                SOME Posix.Error.intr)
   ```
   This behavior is determined dynamically by the value of `Signal.restart`.
2. Signal handlers should always get a chance to run (when outside a critical region). If a system call is interrupted by a signal, then the signal handler will run before the call is restarted or `OS.SysError` is raised; that is, before the `Signal.restart` check.
3. A system call that must be restarted while in a critical section will be restarted with the handled signals blocked (and the previously blocked signals remembered). This encourages the system call to complete, allowing the program to make progress towards leaving the critical section where the signal can be handled. If the system call completes, the set of blocked signals are restored to those previously blocked.

MLtonStructure

The MLton structure contains a lot of functionality that is not available in the Basis Library. As a warning, please keep in mind that the MLton structure and its substructures do change from release to release of MLton.

```
structure MLton:
   sig
      val eq: 'a * 'a -> bool
      val equal: 'a * 'a -> bool
      val hash: 'a -> Word32.word
      val isMLton: bool
      val share: 'a -> unit
      val shareAll: unit -> unit
      val size: 'a -> int

      structure Array: MLTON_ARRAY
      structure BinIO: MLTON_BIN_IO
      structure CharArray: MLTON_MONO_ARRAY where type t = CharArray.array
                                            where type elem = CharArray.elem
      structure CharVector: MLTON_MONO_VECTOR where type t = CharVector.vector
                                              where type elem = CharVector.elem
      structure Cont: MLTON_CONT
      structure Exn: MLTON_EXN
      structure Finalizable: MLTON_FINALIZABLE
      structure GC: MLTON_GC
      structure IntInf: MLTON_INT_INF
      structure Itimer: MLTON_ITIMER
      structure LargeReal: MLTON_REAL where type t = LargeReal.real
      structure LargeWord: MLTON_WORD where type t = LargeWord.word
      structure Platform: MLTON_PLATFORM
      structure Pointer: MLTON_POINTER
      structure ProcEnv: MLTON_PROC_ENV
      structure Process: MLTON_PROCESS
      structure Profile: MLTON_PROFILE
      structure Random: MLTON_RANDOM
      structure Real: MLTON_REAL where type t = Real.real
      structure Real32: sig
                           include MLTON_REAL
                           val castFromWord: Word32.word -> t
                           val castToWord: t -> Word32.word
                        end where type t = Real32.real
      structure Real64: sig
                           include MLTON_REAL
                           val castFromWord: Word64.word -> t
                           val castToWord: t -> Word64.word
                        end where type t = Real64.real
      structure Rlimit: MLTON_RLIMIT
      structure Rusage: MLTON_RUSAGE
      structure Signal: MLTON_SIGNAL
      structure Syslog: MLTON_SYSLOG
      structure TextIO: MLTON_TEXT_IO
      structure Thread: MLTON_THREAD
      structure Vector: MLTON_VECTOR
      structure Weak: MLTON_WEAK
      structure Word: MLTON_WORD where type t = Word.word
      structure Word8: MLTON_WORD where type t = Word8.word
      structure Word16: MLTON_WORD where type t = Word16.word
      structure Word32: MLTON_WORD where type t = Word32.word
      structure Word64: MLTON_WORD where type t = Word64.word
      structure Word8Array: MLTON_MONO_ARRAY where type t = Word8Array.array
                                             where type elem = Word8Array.elem
```

```
    structure Word8Vector: MLTON_MONO_VECTOR where type t = Word8Vector.vector
                                             where type elem = Word8Vector.elem
    structure World: MLTON_WORLD
end
```

Substructures

- MLtonArray
- MLtonBinIO
- MLtonCont
- MLtonExn
- MLtonFinalizable
- MLtonGC
- MLtonIntInf
- MLtonIO
- MLtonItimer
- MLtonMonoArray
- MLtonMonoVector
- MLtonPlatform
- MLtonPointer
- MLtonProcEnv
- MLtonProcess
- MLtonRandom
- MLtonReal
- MLtonRlimit
- MLtonRusage
- MLtonSignal
- MLtonSyslog
- MLtonTextIO
- MLtonThread
- MLtonVector
- MLtonWeak
- MLtonWord
- MLtonWorld

Values

- `eq (x, y)`

  returns true if `x` and `y` are equal as pointers. For simple types like `char`, `int`, and `word`, this is the same as equals. For arrays, datatypes, strings, tuples, and vectors, this is a simple pointer equality. The semantics is a bit murky.

- `equal (x, y)`

  returns true if `x` and `y` are structurally equal. For equality types, this is the same as PolymorphicEquality. For other types, it is a conservative approximation of equivalence.

- `hash x`

  returns a structural hash of `x`. The hash function is consistent between execution of the same program, but may not be consistent between different programs.

- `isMLton`

  is always `true` in a MLton implementation, and is always `false` in a stub implementation.

- `share x`

  maximizes sharing in the heap for the object graph reachable from `x`.

- `shareAll ()`

  maximizes sharing in the heap by sharing space for equivalent immutable objects. A call to `shareAll` performs a major garbage collection, and takes time proportional to the size of the heap.

- `size x`

  returns the amount of heap space (in bytes) taken by the value of `x`, including all objects reachable from `x` by following pointers. It takes time proportional to the size of `x`. See below for an example.

Example of `MLton.size`

This example, `size.sml`, demonstrates the application of `MLton.size` to many different kinds of objects.

```
fun 'a printSize (name: string, value: 'a): unit=
   (print "The size of "
    ; print name
    ; print " is "
    ; print (Int.toString (MLton.size value))
    ; print " bytes.\n")

val l = [1, 2, 3, 4]

val _ =
   (
    printSize ("an int list of length 4", l)
    ; printSize ("a string of length 10", "0123456789")
    ; printSize ("an int array of length 10", Array.tabulate (10, fn _ => 0))
    ; printSize ("a double array of length 10",
                 Array.tabulate (10, fn _ => 0.0))
    ; printSize ("an array of length 10 of 2-ples of ints",
                 Array.tabulate (10, fn i => (i, i + 1)))
    ; printSize ("a useless function", fn _ => 13)
    )

(* This is here so that the list is "useful".
 * If it were removed, then the optimizer (remove-unused-constructors)
 * would remove l entirely.
 *)
val _ = if 10 = foldl (op +) 0 l
```

```
            then ()
        else raise Fail "bug"

local
   open MLton.Cont
in
   val rc: int option t option ref = ref NONE
   val _ =
      case callcc (fn k: int option t => (rc := SOME k; throw (k, NONE))) of
         NONE => ()
       | SOME i => print (concat [Int.toString i, "\n"])
end

val _ = printSize ("a continuation option ref", rc)

val _ =
   case !rc of
      NONE => ()
    | SOME k => (rc := NONE; MLton.Cont.throw (k, SOME 13))
```

Compile and run as usual.

```
% mlton size.sml
% ./size
The size of an int list of length 4 is 48 bytes.
The size of a string of length 10 is 24 bytes.
The size of an int array of length 10 is 52 bytes.
The size of a double array of length 10 is 92 bytes.
The size of an array of length 10 of 2-ples of ints is 92 bytes.
The size of a useless function is 0 bytes.
The size of a continuation option ref is 4544 bytes.
13
The size of a continuation option ref is 8 bytes.
```

Note that sizes are dependent upon the target platform and compiler optimizations.

MLtonSyslog

```
signature MLTON_SYSLOG =
   sig
      type openflag

      val CONS     : openflag
      val NDELAY   : openflag
      val NOWAIT   : openflag
      val ODELAY   : openflag
      val PERROR   : openflag
      val PID      : openflag

      type facility

      val AUTHPRIV : facility
      val CRON     : facility
      val DAEMON   : facility
      val KERN     : facility
      val LOCAL0   : facility
      val LOCAL1   : facility
      val LOCAL2   : facility
      val LOCAL3   : facility
      val LOCAL4   : facility
      val LOCAL5   : facility
      val LOCAL6   : facility
      val LOCAL7   : facility
      val LPR      : facility
      val MAIL     : facility
      val NEWS     : facility
      val SYSLOG   : facility
      val USER     : facility
      val UUCP     : facility

      type loglevel

      val EMERG    : loglevel
      val ALERT    : loglevel
      val CRIT     : loglevel
      val ERR      : loglevel
      val WARNING  : loglevel
      val NOTICE   : loglevel
      val INFO     : loglevel
      val DEBUG    : loglevel

      val closelog: unit -> unit
      val log: loglevel * string -> unit
      val openlog: string * openflag list * facility -> unit
   end
```

`MLton.Syslog` is a complete interface to the system logging facilities. See `man 3 syslog` for more details.

- `closelog ()`

  closes the connection to the system logger.

- `log (l, s)`

  logs message `s` at a loglevel `l`.

- `openlog (name, flags, facility)`

  opens a connection to the system logger. `name` will be prefixed to each message, and is typically set to the program name.

MLtonTextIO

```
signature MLTON_TEXT_IO = MLTON_IO
```

See MLtonIO.

MLtonThread

```
signature MLTON_THREAD =
   sig
      structure AtomicState:
         sig
            datatype t = NonAtomic | Atomic of int
         end

      val atomically: (unit -> 'a) -> 'a
      val atomicBegin: unit -> unit
      val atomicEnd: unit -> unit
      val atomicState: unit -> AtomicState.t

      structure Runnable:
         sig
            type t
         end

      type 'a t

      val atomicSwitch: ('a t -> Runnable.t) -> 'a
      val new: ('a -> unit) -> 'a t
      val prepend: 'a t * ('b -> 'a) -> 'b t
      val prepare: 'a t * 'a -> Runnable.t
      val switch: ('a t -> Runnable.t) -> 'a
   end
```

`MLton.Thread` provides access to MLton's user-level thread implementation (i.e. not OS-level threads). Threads are lightweight data structures that represent a paused computation. Runnable threads are threads that will begin or continue computing when `switch`-ed to. `MLton.Thread` does not include a default scheduling mechanism, but it can be used to implement both preemptive and non-preemptive threads.

- `type AtomicState.t`

  the type of atomic states.

- `atomically f`

  runs `f` in a critical section.

- `atomicBegin ()`

  begins a critical section.

- `atomicEnd ()`

  ends a critical section.

- `atomicState ()`

  returns the current atomic state.

- `type Runnable.t`

  the type of threads that can be resumed.

- `type 'a t`

  the type of threads that expect a value of type `'a`.

- `atomicSwitch f`

  like `switch`, but assumes an atomic calling context. Upon `switch`-ing back to the current thread, an implicit `atomicEnd` is performed.

- `new f`

  creates a new thread that, when run, applies `f` to the value given to the thread. `f` must terminate by `switch`ing to another thread or exiting the process.

- `prepend (t, f)`

  creates a new thread (destroying `t` in the process) that first applies `f` to the value given to the thread and then continues with `t`. This is a constant time operation.

- `prepare (t, v)`

  prepares a new runnable thread (destroying `t` in the process) that will evaluate `t` on `v`.

- `switch f`

  applies `f` to the current thread to get `rt`, and then start running thread `rt`. It is an error for `f` to perform another `switch`. `f` is guaranteed to run atomically.

Example of non-preemptive threads

```
structure Queue:
   sig
      type 'a t

      val new: unit -> 'a t
      val enque: 'a t * 'a -> unit
      val deque: 'a t -> 'a option
   end =
   struct
      datatype 'a t = T of {front: 'a list ref, back: 'a list ref}

      fun new () = T {front = ref [], back = ref []}

      fun enque (T {back, ...}, x) = back := x :: !back

      fun deque (T {front, back}) =
         case !front of
            [] => (case !back of
                      [] => NONE
                    | l => let val l = rev l
                           in case l of
                                 [] => raise Fail "deque"
                               | x :: l => (back := []; front := l; SOME x)
                           end)
          | x :: l => (front := l; SOME x)
   end

structure Thread:
   sig
      val exit: unit -> 'a
      val run: unit -> unit
      val spawn: (unit -> unit) -> unit
      val yield: unit -> unit
   end =
   struct
      open MLton
      open Thread

      val topLevel: Thread.Runnable.t option ref = ref NONE

      local
         val threads: Thread.Runnable.t Queue.t = Queue.new ()
```

```
      in
         fun ready (t: Thread.Runnable.t) : unit =
            Queue.enque(threads, t)
         fun next () : Thread.Runnable.t =
            case Queue.deque threads of
               NONE => valOf (!topLevel)
             | SOME t => t
      end

      fun 'a exit (): 'a = switch (fn _ => next ())

      fun new (f: unit -> unit): Thread.Runnable.t =
         Thread.prepare
         (Thread.new (fn () => ((f () handle _ => exit ())
                                 ; exit ())),
          ())

      fun schedule t = (ready t; next ())

      fun yield (): unit = switch (fn t => schedule (Thread.prepare (t, ())))

      val spawn = ready o new

      fun run(): unit =
         (switch (fn t =>
                  (topLevel := SOME (Thread.prepare (t, ()))
                   ; next()))
          ; topLevel := NONE)
   end

val rec loop =
   fn 0 => ()
    | n => (print(concat[Int.toString n, "\n"])
            ; Thread.yield()
            ; loop(n - 1))

val rec loop' =
   fn 0 => ()
    | n => (Thread.spawn (fn () => loop n); loop' (n - 2))

val _ = Thread.spawn (fn () => loop' 10)

val _ = Thread.run ()

val _ = print "success\n"
```

Example of preemptive threads

```
structure Queue:
   sig
      type 'a t

      val new: unit -> 'a t
      val enque: 'a t * 'a -> unit
      val deque: 'a t -> 'a option
   end =
   struct
      datatype 'a t = T of {front: 'a list ref, back: 'a list ref}

      fun new () = T {front = ref [], back = ref []}
```

```
      fun enque (T {back, ...}, x) = back := x :: !back

      fun deque (T {front, back}) =
         case !front of
            [] => (case !back of
                      [] => NONE
                    | l => let val l = rev l
                           in case l of
                              [] => raise Fail "deque"
                            | x :: l => (back := []; front := l; SOME x)
                           end)
          | x :: l => (front := l; SOME x)
   end

structure Thread:
   sig
      val exit: unit -> 'a
      val run: unit -> unit
      val spawn: (unit -> unit) -> unit
      val yield: unit -> unit
   end =
   struct
      open Posix.Signal
      open MLton
      open Itimer Signal Thread

      val topLevel: Thread.Runnable.t option ref = ref NONE

      local
         val threads: Thread.Runnable.t Queue.t = Queue.new ()
      in
         fun ready (t: Thread.Runnable.t) : unit =
            Queue.enque(threads, t)
         fun next () : Thread.Runnable.t =
            case Queue.deque threads of
               NONE => valOf (!topLevel)
             | SOME t => t
      end

      fun 'a exit (): 'a = switch (fn _ => next ())

      fun new (f: unit -> unit): Thread.Runnable.t =
         Thread.prepare
         (Thread.new (fn () => ((f () handle _ => exit ())
                                ; exit ())),
          ())

      fun schedule t = (ready t; next ())

      fun yield (): unit = switch (fn t => schedule (Thread.prepare (t, ())))

      val spawn = ready o new

      fun setItimer t =
         Itimer.set (Itimer.Real,
                     {value = t,
                      interval = t})

      fun run (): unit =
         (switch (fn t =>
                  (topLevel := SOME (Thread.prepare (t, ()))
```

```
                    ; new (fn () => (setHandler (alrm, Handler.handler schedule)
                                     ; setItimer (Time.fromMilliseconds 20)))))
          ; setItimer Time.zeroTime
          ; ignore alrm
          ; topLevel := NONE)
   end

val rec delay =
   fn 0 => ()
    | n => delay (n - 1)

val rec loop =
   fn 0 => ()
    | n => (delay 500000; loop (n - 1))

val rec loop' =
   fn 0 => ()
    | n => (Thread.spawn (fn () => loop n); loop' (n - 1))

val _ = Thread.spawn (fn () => loop' 10)

val _ = Thread.run ()

val _ = print "success\n"
```

MLtonVector

```
signature MLTON_VECTOR =
   sig
      val create: int -> {done: unit -> 'a vector,
                          sub: int -> 'a,
                          update: int * 'a -> unit}
      val unfoldi: int * 'b * (int * 'b -> 'a * 'b) -> 'a vector * 'b
   end
```

- `create n`

  initiates the construction a vector v of length `n`, returning functions to manipulate the vector. The `done` function may be called to return the created vector; it is an error to call `done` before all entries have been initialized; it is an error to call `done` after having called `done`. The `sub` function may be called to return an initialized vector entry; it is not an error to call `sub` after having called `done`. The `update` function may be called to initialize a vector entry; it is an error to call `update` after having called `done`. One must initialize vector entries in order from lowest to highest; that is, before calling `update (i, x)`, one must have already called `update (j, x)` for all `j` in `[0, i)`. The `done`, `sub`, and `update` functions are all constant-time operations.

- `unfoldi (n, b, f)`

  constructs a vector v of length `n`, whose elements v_i are determined by the equations $b_0 = b$ and $(v_i, b_{i+1}) = f(i, b_i)$.

MLtonWeak

```
signature MLTON_WEAK =
   sig
      type 'a t

      val get: 'a t -> 'a option
      val new: 'a -> 'a t
   end
```

A weak pointer is a pointer to an object that is nulled if the object becomes unreachable due to garbage collection. The weak pointer does not itself cause the object it points to be retained by the garbage collector — only other strong pointers can do that. For objects that are not allocated in the heap, like integers, a weak pointer will always be nulled. So, if `w:int Weak.t`, then `Weak.get w` =NONE.

- `type 'a t`

  the type of weak pointers to objects of type `'a`

- `get w`

  returns `NONE` if the object pointed to by `w` no longer exists. Otherwise, returns `SOME` of the object pointed to by `w`.

- `new x`

  returns a weak pointer to `x`.

MLtonWord

```
signature MLTON_WORD =
   sig
      type t

      val bswap: t -> t
      val rol: t * word -> t
      val ror: t * word -> t
   end
```

- `type t`

  the type of words. For `MLton.LargeWord` this is `LargeWord.word`, for `MLton.Word` this is `Word.word`, for `MLton.Word8` this is `Word8.word`, for `MLton.Word16` this is `Word16.word`, for `MLton.Word32` this is `Word32.word`, for `MLton.Word64` this is `Word64.word`.

- `bswap w`

  byte swap.

- `rol (w, w')`

  rotates left (circular).

- `ror (w, w')`

  rotates right (circular).

MLtonWorld

```
signature MLTON_WORLD =
   sig
      datatype status = Clone | Original

      val load: string -> 'a
      val save: string -> status
      val saveThread: string * Thread.Runnable.t -> unit
   end
```

- `datatype status`

  specifies whether a world is original or restarted (a clone).

- `load f`

  loads the saved computation from file `f`.

- `save f`

  saves the entire state of the computation to the file `f`. The computation can then be restarted at a later time using `World.load` or the `load-world` runtime option. The call to `save` in the original computation returns `Original` and the call in the restarted world returns `Clone`.

- `saveThread (f, rt)`

  saves the entire state of the computation to the file `f` that will resume with thread `rt` upon restart.

Notes

Executables that save and load worlds are incompatible with address space layout randomization (ASLR) of the executable (though, not of shared libraries). The state of a computation includes addresses into the code and data segments of the executable (e.g., static runtime-system data, return addresses); such addresses are invalid when interpreted by the executable loaded at a different base address.

Executables that save and load worlds should be compiled with an option to suppress the generation of position-independent executables.

- Darwin 11 (Mac OS X Lion) and higher : `-link-opt -fno-PIE`

Example

Suppose that `save-world.sml` contains the following.

```
open MLton.World

val _ =
   case save "world" of
      Original => print "I am the original\n"
    | Clone => print "I am the clone\n"
```

Then, if we compile `save-world.sml` and run it, the `Original` branch will execute, and a file named `world` will be created.

```
% mlton save-world.sml
% ./save-world
I am the original
```

We can then load `world` using the `load-world` run time option.

```
% ./save-world @MLton load-world world --
I am the clone
```

MLULex

MLULex is a scanner generator for Standard ML.

Also see

- MLAntlr
- MLLPTLibrary
- OwensEtAl09

MLYacc

MLYacc is a parser generator for Standard ML modeled after the Yacc parser generator.

A version of MLYacc, ported from the SML/NJ sources, is distributed with MLton.

Also see

- `mlyacc.pdf`
- MLLex
- TarditiAppel00
- Price09

Monomorphise

Monomorphise is a translation pass from the XML IntermediateLanguage to the SXML IntermediateLanguage.

Description

Monomorphisation eliminates polymorphic values and datatype declarations by duplicating them for each type at which they are used.

Consider the following XML program.

```
datatype 'a t = T of 'a
fun 'a f (x: 'a) = T x
val a = f 1
val b = f 2
val z = f (3, 4)
```

The result of monomorphising this program is the following SXML program:

```
datatype t1 = T1 of int
datatype t2 = T2 of int * int
fun f1 (x: int) = T1 x
fun f2 (x: int * int) = T2 x
val a = f1 1
val b = f1 2
val z = f2 (3, 4)
```

Implementation

- monomorphise.sig
- monomorphise.fun

Details and Notes

The monomorphiser works by making one pass over the entire program. On the way down, it creates a cache for each variable declared in a polymorphic declaration that maps a lists of type arguments to a new variable name. At a variable reference, it consults the cache (based on the types the variable is applied to). If there is already an entry in the cache, it is used. If not, a new entry is created. On the way up, the monomorphiser duplicates a variable declaration for each entry in the cache.

As with variables, the monomorphiser records all of the type at which constructors are used. After the entire program is processed, the monomorphiser duplicates each datatype declaration and its associated constructors.

The monomorphiser duplicates all of the functions declared in a `fun` declaration as a unit. Consider the following program

```
fun 'a f (x: 'a) = g x
and g (y: 'a) = f y
val a = f 13
val b = g 14
val c = f (1, 2)
```

and its monomorphisation

```
fun f1 (x: int) = g1 x
and g1 (y: int) = f1 y
fun f2 (x : int * int) = g2 x
and g2 (y : int * int) = f2 y
val a = f1 13
val b = g1 14
val c = f2 (1, 2)
```

Pathological datatype declarations

SML allows a pathological polymorphic datatype declaration in which recursive uses of the defined type constructor are applied to different type arguments than the definition. This has been disallowed by others on type theoretic grounds. A canonical example is the following.

```
datatype 'a t = A of 'a | B of ('a * 'a) t
val z : int t = B (B (A ((1, 2), (3, 4))))
```

The presence of the recursion in the datatype declaration might appear to cause the need for the monomorphiser to create an infinite number of types. However, due to the absence of polymorphic recursion in SML, there are in fact only a finite number of instances of such types in any given program. The monomorphiser translates the above program to the following one.

```
datatype t1 = B1 of t2
datatype t2 = B2 of t3
datatype t3 = A3 of (int * int) * (int * int)
val z : int t = B1 (B2 (A3 ((1, 2), (3, 4))))
```

It is crucial that the monomorphiser be allowed to drop unused constructors from datatype declarations in order for the translation to terminate.

MoscowML

Moscow ML is a Standard ML implementation. It is a byte-code compiler, so it compiles code quickly, but the code runs slowly. See Performance.

Multi

Multi is an analysis pass for the SSA IntermediateLanguage, invoked from ConstantPropagation and LocalRef.

Description

This pass analyzes the control flow of a SSA program to determine which SSA functions and blocks might be executed more than once or by more than one thread. It also determines when a program uses threads and when functions and blocks directly or indirectly invoke `Thread_copyCurrent`.

Implementation

- `multi.sig`
- `multi.fun`

Details and Notes

Mutable

Mutable is an adjective meaning "can be modified". In Standard ML, ref cells and arrays are mutable, while all other values are immutable.

NeedsReview

This page documents some patches and bug fixes that need additional review by experienced developers:

- Bug in transparent signature match:
  - What is an *original* interface and why does the equivalence of original interfaces implies the equivalence of the actual interfaces?
  - http://www.mlton.org/pipermail/mlton/2007-September/029991.html
  - http://www.mlton.org/pipermail/mlton/2007-September/029995.html
  - SVN Revision: `r6046`
- Bug in DeepFlatten pass:
  - Should we allow argument to `Weak_new` to be flattened?
  - SVN Revision: `r6189` (regression test demonstrating bug)
  - SVN Revision: `r6191`

NumericLiteral

Numeric literals in Standard ML can be written in either decimal or hexadecimal notation. Sometimes it can be convenient to write numbers down in other bases. Fortunately, using Fold, it is possible to define a concise syntax for numeric literals that allows one to write numeric constants in any base and of various types (`int`, `IntInf.int`, `word`, and more).

We will define constants `I`, `II`, `W`, and ` so that, for example,

```
I 10 `1`2`3 $
```

denotes `123:int` in base 10, while

```
II 8 `2`3 $
```

denotes `19:IntInf.int` in base 8, and

```
W 2 `1`1`0`1 $
```

denotes `0w13:word`.

Here is the code.

```
structure Num =
   struct
      fun make (op *, op +, i2x) iBase =
          let
             val xBase = i2x iBase
          in
             Fold.fold
                ((i2x 0,
                  fn (i, x) =>
                     if 0 <= i andalso i < iBase then
                        x * xBase + i2x i
                     else
                        raise Fail (concat
                                       ["Num: ", Int.toString i,
                                        " is not a valid\
                                        \ digit in base ",
                                        Int.toString iBase])),
                 fst)
          end

      fun I  ? = make (op *, op +, id) ?
      fun II ? = make (op *, op +, IntInf.fromInt) ?
      fun W  ? = make (op *, op +, Word.fromInt) ?

      fun ` ? = Fold.step1 (fn (i, (x, step)) =>
                               (step (i, x), step)) ?

      val a = 10
      val b = 11
      val c = 12
      val d = 13
      val e = 14
      val f = 15
   end
```

where

```
fun fst (x, _) = x
```

The idea is for the fold to start with zero and to construct the result one digit at a time, with each stepper multiplying the previous result by the base and adding the next digit. The code is abstracted in two different ways for extra generality. First, the `make` function abstracts over the various primitive operations (addition, multiplication, etc) that are needed to construct a number. This allows the same code to be shared for constants `I`, `II`, `W` used to write down the various numeric types. It also allows users to add new constants for additional numeric types, by supplying the necessary arguments to make.

Second, the step function, `` ` ``, is abstracted over the actual construction operation, which is created by make, and passed along the fold. This allows the same constant, `` ` ``, to be used for all numeric types. The alternative approach, having a different step function for each numeric type, would be more painful to use.

On the surface, it appears that the code checks the digits dynamically to ensure they are valid for the base. However, MLton will simplify everything away at compile time, leaving just the final numeric constant.

ObjectOrientedProgramming

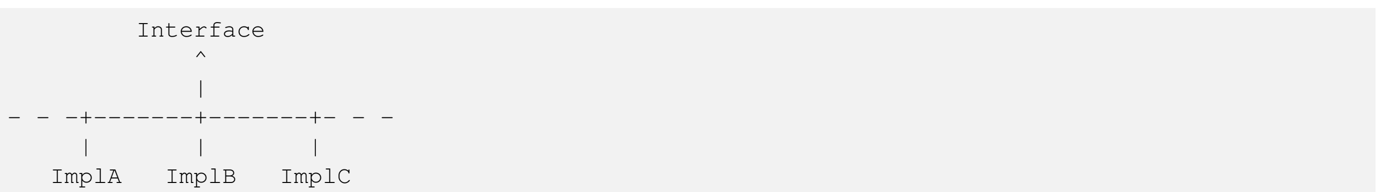
Standard ML does not have explicit support for object-oriented programming. Here are some papers that show how to express certain object-oriented concepts in SML.

- OO Programming styles in ML
- Object-oriented programming and Standard ML
- mGTK: An SML binding of Gtk+
- Phantom Types and Subtyping

The question of OO programming in SML comes up every now and then. The following discusses a simple object-oriented (OO) programming technique in Standard ML. The reader is assumed to be able to read Java and SML code.

Motivation

SML doesn't provide subtyping, but it does provide parametric polymorphism, which can be used to encode some forms of subtyping. Most articles on OO programming in SML concentrate on such encoding techniques. While those techniques are interesting — and it is recommended to read such articles — and sometimes useful, it seems that basically all OO gurus agree that (deep) subtyping (or inheritance) hierarchies aren't as practical as they were thought to be in the early OO days. "Good", flexible, "OO" designs tend to have a flat structure



and deep inheritance hierarchies

```
ClassA
  ^
  |
ClassB
  ^
  |
ClassC
  ^
  |
```

tend to be signs of design mistakes. There are good underlying reasons for this, but a thorough discussion is not in the scope of this article. However, the point is that perhaps the encoding of subtyping is not as important as one might believe. In the following we ignore subtyping and rather concentrate on a very simple and basic dynamic dispatch technique.

Dynamic Dispatch Using a Recursive Record of Functions

Quite simply, the basic idea is to implement a "virtual function table" using a record that is wrapped inside a (possibly recursive) datatype. Let's first take a look at a simple concrete example.

Consider the following Java interface:

```
public interface Counter {
  public void inc();
  public int get();
}
```

We can translate the `Counter` interface to SML as follows:

```
datatype counter = Counter of {inc : unit -> unit, get : unit -> int}
```

Each value of type `counter` can be thought of as an object that responds to two messages `inc` and `get`. To actually send messages to a counter, it is useful to define auxiliary functions

```
local
   fun mk m (Counter t) = m t ()
in
   val cGet = mk#get
   val cInc = mk#inc
end
```

that basically extract the "function table" `t` from a counter object and then select the specified method `m` from the table.

Let's then implement a simple function that increments a counter until a given maximum is reached:

```
fun incUpto counter max = while cGet counter < max do cInc counter
```

You can easily verify that the above code compiles even without any concrete implementation of a counter, thus it is clear that it doesn't depend on a particular counter implementation.

Let's then implement a couple of counters. First consider the following Java class implementing the `Counter` interface given earlier.

```
public class BasicCounter implements Counter {
  private int cnt;
  public BasicCounter(int initialCnt) { this.cnt = initialCnt; }
  public void inc() { this.cnt += 1; }
  public int get() { return this.cnt; }
}
```

We can translate the above to SML as follows:

```
fun newBasicCounter initialCnt = let
       val cnt = ref initialCnt
    in
       Counter {inc = fn () => cnt := !cnt + 1,
                get = fn () => !cnt}
    end
```

The SML function `newBasicCounter` can be described as a constructor function for counter objects of the `BasicCounter` "class". We can also have other counter implementations. Here is the constructor for a counter decorator that logs messages:

```
fun newLoggedCounter counter =
    Counter {inc = fn () => (print "inc\n" ; cInc counter),
             get = fn () => (print "get\n" ; cGet counter)}
```

The `incUpto` function works just as well with objects of either class:

```
val aCounter = newBasicCounter 0
val () = incUpto aCounter 5
val () = print (Int.toString (cGet aCounter) ^"\n")

val aCounter = newLoggedCounter (newBasicCounter 0)
val () = incUpto aCounter 5
val () = print (Int.toString (cGet aCounter) ^"\n")
```

In general, a dynamic dispatch interface is represented as a record type wrapped inside a datatype. Each field of the record corresponds to a public method or field of the object:

```
datatype interface =
   Interface of {method : t1 -> t2,
                 immutableField : t,
                 mutableField : t ref}
```

The reason for wrapping the record inside a datatype is that records, in SML, can not be recursive. However, SML datatypes can be recursive. A record wrapped in a datatype can contain fields that contain the datatype. For example, an interface such as `Cloneable`

```
datatype cloneable = Cloneable of {clone : unit -> cloneable}
```

can be represented using recursive datatypes.

Like in OO languages, interfaces are abstract and can not be instantiated to produce objects. To be able to instantiate objects, the constructors of a concrete class are needed. In SML, we can implement constructors as simple functions from arbitrary arguments to values of the interface type. Such a constructor function can encapsulate arbitrary private state and functions using lexical closure. It is also easy to share implementations of methods between two or more constructors.

While the `Counter` example is rather trivial, it should not be difficult to see that this technique quite simply doesn't require a huge amount of extra verbiage and is more than usable in practice.

SML Modules and Dynamic Dispatch

One might wonder about how SML modules and the dynamic dispatch technique work together. Let's investigate! Let's use a simple dispenser framework as a concrete example. (Note that this isn't intended to be an introduction to the SML module system.)

Programming with SML Modules

Using SML signatures we can specify abstract data types (ADTs) such as dispensers. Here is a signature for an "abstract" functional (as opposed to imperative) dispenser:

```
signature ABSTRACT_DISPENSER = sig
   type 'a t
   val isEmpty : 'a t -> bool
   val push : 'a * 'a t -> 'a t
   val pop : 'a t -> ('a * 'a t) option
end
```

The term "abstract" in the name of the signature refers to the fact that the signature gives no way to instantiate a dispenser. It has nothing to do with the concept of abstract data types.

Using SML functors we can write "generic" algorithms that manipulate dispensers of an unknown type. Here are a couple of very simple algorithms:

```
functor DispenserAlgs (D : ABSTRACT_DISPENSER) = struct
   open D

   fun pushAll (xs, d) = foldl push d xs

   fun popAll d = let
          fun lp (xs, NONE) = rev xs
            | lp (xs, SOME (x, d)) = lp (x::xs, pop d)
       in
          lp ([], pop d)
       end

   fun cp (from, to) = pushAll (popAll from, to)
end
```

As one can easily verify, the above compiles even without any concrete dispenser structure. Functors essentially provide a form a static dispatch that one can use to break compile-time dependencies.

We can also give a signature for a concrete dispenser

```
signature DISPENSER = sig
   include ABSTRACT_DISPENSER
   val empty : 'a t
end
```

and write any number of concrete structures implementing the signature. For example, we could implement stacks

```
structure Stack :> DISPENSER = struct
   type 'a t = 'a list
   val empty = []
   val isEmpty = null
   val push = op ::
   val pop = List.getItem
end
```

and queues

```
structure Queue :> DISPENSER = struct
   datatype 'a t = T of 'a list * 'a list
   val empty = T ([], [])
   val isEmpty = fn T ([], _) => true | _ => false
   val normalize = fn ([], ys) => (rev ys, []) | q => q
   fun push (y, T (xs, ys)) = T (normalize (xs, y::ys))
   val pop = fn (T (x::xs, ys)) => SOME (x, T (normalize (xs, ys))) | _ => NONE
end
```

One can now write code that uses either the `Stack` or the `Queue` dispenser. One can also instantiate the previously defined functor to create functions for manipulating dispensers of a type:

```
structure S = DispenserAlgs (Stack)
val [4,3,2,1] = S.popAll (S.pushAll ([1,2,3,4], Stack.empty))

structure Q = DispenserAlgs (Queue)
val [1,2,3,4] = Q.popAll (Q.pushAll ([1,2,3,4], Queue.empty))
```

There is no dynamic dispatch involved at the module level in SML. An attempt to do dynamic dispatch

```
val q = Q.push (1, Stack.empty)
```

will give a type error.

Combining SML Modules and Dynamic Dispatch

Let's then combine SML modules and the dynamic dispatch technique introduced in this article. First we define an interface for dispensers:

```
structure Dispenser = struct
   datatype 'a t =
      I of {isEmpty : unit -> bool,
            push : 'a -> 'a t,
            pop : unit -> ('a * 'a t) option}

   fun O m (I t) = m t

   fun isEmpty t = O#isEmpty t ()
   fun push (v, t) = O#push t v
   fun pop t = O#pop t ()
end
```

The `Dispenser` module, which we can think of as an interface for dispensers, implements the `ABSTRACT_DISPENSER` signature using the dynamic dispatch technique, but we leave the signature ascription until later.

Then we define a `DispenserClass` functor that makes a "class" out of a given dispenser module:

```
functor DispenserClass (D : DISPENSER) : DISPENSER = struct
   open Dispenser

   fun make d =
       I {isEmpty = fn () => D.isEmpty d,
          push = fn x => make (D.push (x, d)),
          pop = fn () =>
                   case D.pop d of
                      NONE => NONE
                    | SOME (x, d) => SOME (x, make d)}

   val empty =
       I {isEmpty = fn () => true,
          push = fn x => make (D.push (x, D.empty)),
          pop = fn () => NONE}
end
```

Finally we seal the `Dispenser` module:

```
structure Dispenser : ABSTRACT_DISPENSER = Dispenser
```

This isn't necessary for type safety, because the unsealed `Dispenser` module does not allow one to break encapsulation, but makes sure that only the `DispenserClass` functor can create dispenser classes (because the constructor `Dispenser.I` is no longer accessible).

Using the `DispenserClass` functor we can turn any concrete dispenser module into a dispenser class:

```
structure StackClass = DispenserClass (Stack)
structure QueueClass = DispenserClass (Queue)
```

Each dispenser class implements the same dynamic dispatch interface and the `ABSTRACT_DISPENSER` -signature.

Because the dynamic dispatch `Dispenser` module implements the `ABSTRACT_DISPENSER`-signature, we can use it to instantiate the `DispenserAlgs`-functor:

```
structure D = DispenserAlgs (Dispenser)
```

The resulting `D` module, like the `Dispenser` module, works with any dispenser class and uses dynamic dispatch:

```
val [4, 3, 2, 1] = D.popAll (D.pushAll ([1, 2, 3, 4], StackClass.empty))
val [1, 2, 3, 4] = D.popAll (D.pushAll ([1, 2, 3, 4], QueueClass.empty))
```

OCaml

OCaml is a variant of ML and is similar to Standard ML.

OCaml and SML

Here's a comparison of some aspects of the OCaml and SML languages.

- Standard ML has a formal Definition, while OCaml is specified by its lone implementation and informal documentation.
- Standard ML has a number of compilers, while OCaml has only one.
- OCaml has built-in support for object-oriented programming, while Standard ML does not (however, see ObjectOrientedProgramming).
- Andreas Rossberg has a side-by-side comparison of the syntax of SML and OCaml.
- Adam Chlipala has a point-by-point comparison of OCaml and SML.

OCaml and MLton

Here's a comparison of some aspects of OCaml and MLton.

- Performance
  - Both OCaml and MLton have excellent performance.
  - MLton performs extensive WholeProgramOptimization, which can provide substantial improvements in large, modular programs.
  - MLton uses native types, like 32-bit integers, without any penalty due to tagging or boxing. OCaml uses 31-bit integers with a penalty due to tagging, and 32-bit integers with a penalty due to boxing.
  - MLton uses native types, like 64-bit floats, without any penalty due to boxing. OCaml, in some situations, boxes 64-bit floats.
  - MLton represents arrays of all types unboxed. In OCaml, only arrays of 64-bit floats are unboxed, and then only when it is syntactically apparent.
  - MLton represents records compactly by reordering and packing the fields.
  - In MLton, polymorphic and monomorphic code have the same performance. In OCaml, polymorphism can introduce a performance penalty.
  - In MLton, module boundaries have no impact on performance. In OCaml, moving code between modules can cause a performance penalty.
  - MLton's ForeignFunctionInterface is simpler than OCaml's.
- Tools
  - OCaml has a debugger, while MLton does not.
  - OCaml supports separate compilation, while MLton does not.
  - OCaml compiles faster than MLton.
  - MLton supports profiling of both time and allocation.
- Libraries
  - OCaml has more available libraries.
- Community
  - OCaml has a larger community than MLton.
  - MLton has a very responsive developer list.

OpenGL

There are at least two interfaces to OpenGL for MLton/SML, both of which should be considered alpha quality.

- MikeThomas built a low-level interface, directly translating many of the functions, covering GL, GLU, and GLUT. This is available in the MLton Sources: `opengl`. The code contains a number of small, standard OpenGL examples translated to SML.
- ChrisClearwater has written at least an interface to GL, and possibly more. See
  - http://mlton.org/pipermail/mlton/2005-January/026669.html

Contact us for more information or an update on the status of these projects.

OperatorPrecedence

Standard ML has a built in notion of precedence for certain symbols. Every program that includes the Basis Library automatically gets the following infix declarations. Higher number indicates higher precedence.

```
infix 7 * / mod div
infix 6 + - ^
infixr 5 :: @
infix 4 = <> > >= < <=
infix 3 := o
infix 0 before
```

OptionalArguments

Standard ML does not have built-in support for optional arguments. Nevertheless, using Fold, it is easy to define functions that take optional arguments.

For example, suppose that we have the following definition of a function `f`.

```
fun f (i, r, s) =
   concat [Int.toString i, ", ", Real.toString r, ", ", s]
```

Using the `OptionalArg` structure described below, we can define a function `f'`, an optionalized version of `f`, that takes 0, 1, 2, or 3 arguments. Embedded within `f'` will be default values for `i`, `r`, and `s`. If `f'` gets no arguments, then all the defaults are used. If `f'` gets one argument, then that will be used for `i`. Two arguments will be used for `i` and `r` respectively. Three arguments will override all default values. Calls to `f'` will look like the following.

```
f' $
f' `2 $
f' `2 `3.0 $
f' `2 `3.0 `"four" $
```

The optional argument indicator, `` ` ``, is not special syntax --- it is a normal SML value, defined in the `OptionalArg` structure below.

Here is the definition of `f'` using the `OptionalArg` structure, in particular, `OptionalArg.make` and `OptionalArg.D`.

```
val f' =
   fn z =>
   let open OptionalArg in
      make (D 1) (D 2.0) (D "three") $
   end (fn i & r & s => f (i, r, s))
   z
```

The definition of `f'` is eta expanded as with all uses of fold. A call to `OptionalArg.make` is supplied with a variable number of defaults (in this case, three), the end-of-arguments terminator, `$`, and the function to run, taking its arguments as an n-ary product. In this case, the function simply converts the product to an ordinary tuple and calls `f`. Often, the function body will simply be written directly.

In general, the definition of an optional-argument function looks like the following.

```
val f =
   fn z =>
   let open OptionalArg in
      make (D <default1>) (D <default2>) ... (D <defaultn>) $
   end (fn x1 & x2 & ... & xn =>
        <function code goes here>)
   z
```

Here is the definition of `OptionalArg`.

```
structure OptionalArg =
   struct
      val make =
         fn z =>
         Fold.fold
         ((id, fn (f, x) => f x),
          fn (d, r) => fn func =>
          Fold.fold ((id, d ()), fn (f, d) =>
                     let
                        val d & () = r (id, f d)
                     in
                        func d
                     end))
```

```
      z

   fun D d = Fold.step0 (fn (f, r) =>
                       (fn ds => f (d & ds),
                        fn (f, a & b) => r (fn x => f a & x, b)))

   val ` =
      fn z =>
      Fold.step1 (fn (x, (f, _ & d)) => (fn d => f (x & d), d))
      z
end
```

`OptionalArg.make` uses a nested fold. The first `fold` accumulates the default values in a product, associated to the right, and a reversal function that converts a product (of the same arity as the number of defaults) from right associativity to left associativity. The accumulated defaults are used by the second fold, which recurs over the product, replacing the appropriate component as it encounters optional arguments. The second fold also constructs a "fill" function, `f`, that is used to reconstruct the product once the end-of-arguments is reached. Finally, the finisher reconstructs the product and uses the reversal function to convert the product from right associative to left associative, at which point it is passed to the user-supplied function.

Much of the complexity comes from the fact that while recurring over a product from left to right, one wants it to be right-associative, e.g., look like

```
a & (b & (c & d))
```

but the user function in the end wants the product to be left associative, so that the product argument pattern can be written without parentheses (since `&` is left associative).

Labelled optional arguments

In addition to the positional optional arguments described above, it is sometimes useful to have labelled optional arguments. These allow one to define a function, `f`, with defaults, say `a` and `b`. Then, a caller of `f` can supply values for `a` and `b` by name. If no value is supplied then the default is used.

Labelled optional arguments are a simple extension of FunctionalRecordUpdate using post composition. Suppose, for example, that one wants a function `f` with labelled optional arguments `a` and `b` with default values `0` and `0.0` respectively. If one has a functional-record-update function `updateAB` for records with `a` and `b` fields, then one can define `f` in the following way.

```
val f =
   fn z =>
   Fold.post
   (updateAB {a = 0, b = 0.0},
    fn {a, b} => print (concat [Int.toString a, " ",
                               Real.toString b, "\n"]))
   z
```

The idea is that `f` is the post composition (using `Fold.post`) of the actual code for the function with a functional-record updater that starts with the defaults.

Here are some example calls to `f`.

```
val () = f $
val () = f (U#a 13) $
val () = f (U#a 13) (U#b 17.5) $
val () = f (U#b 17.5) (U#a 13) $
```

Notice that a caller can supply neither of the arguments, either of the arguments, or both of the arguments, and in either order. All that matter is that the arguments be labelled correctly (and of the right type, of course).

Here is another example.

```
val f =
   fn z =>
   Fold.post
   (updateBCD {b = 0, c = 0.0, d = "<>"},
    fn {b, c, d} =>
    print (concat [Int.toString b, " ",
                   Real.toString c, " ",
                   d, "\n"]))
   z
```

Here are some example calls.

```
val () = f $
val () = f (U#d "goodbye") $
val () = f (U#d "hello") (U#b 17) (U#c 19.3) $
```

Overloading

In Standard ML, constants (like `13`, `0w13`, `13.0`) are overloaded, meaning that they can denote a constant of the appropriate type as determined by context. SML defines the overloading classes *Int*, *Real*, and *Word*, which denote the sets of types that integer, real, and word constants may take on. In MLton, these are defined as follows.

Int	`Int2.int`, `Int3.int`, ... `Int32.int`, `Int64.int`, `Int.int`, `IntInf.int`, `LargeInt.int`, `FixedInt.int`, `Position.int`
Real	`Real32.real`, `Real64.real`, `Real.real`, `LargeReal.real`
Word	`Word2.word`, `Word3.word`, ... `Word32.word`, `Word64.word`, `Word.word`, `LargeWord.word`, `SysWord.word`

The Definition allows flexibility in how much context is used to resolve overloading. It says that the context is *no larger than the smallest enclosing structure-level declaration*, but that *an implementation may require that a smaller context determines the type*. MLton uses the largest possible context allowed by SML in resolving overloading. If the type of a constant is not determined by context, then it takes on a default type. In MLton, these are defined as follows.

Int	`Int.int`
Real	`Real.real`
Word	`Word.word`

Other implementations may use a smaller context or different default types.

Also see

- discussion of overloading in the Basis Library

Examples

- The following program is rejected.

```
structure S:
   sig
      val x: Word8.word
   end =
   struct
      val x = 0w0
   end
```

The smallest enclosing structure declaration for `0w0` is `val x =0w0`. Hence, `0w0` receives the default type for words, which is `Word.word`.

PackedRepresentation

PackedRepresentation is an analysis pass for the SSA2 IntermediateLanguage, invoked from ToRSSA.

Description

This pass analyzes a SSA2 program to compute a packed representation for each object.

Implementation

- `representation.sig`
- `packed-representation.fun`

Details and Notes

Has a special case to make sure that `true` is represented as `1` and `false` is represented as `0`.

ParallelMove

ParallelMove is a rewrite pass, agnostic in the IntermediateLanguage which it produces.

Description

This function computes a sequence of individual moves to effect a parallel move (with possibly overlapping froms and tos).

Implementation

- `parallel-move.sig`
- `parallel-move.fun`

Details and Notes

Performance

This page compares the performance of a number of SML compilers on a range of benchmarks.

This page compares the following SML compiler versions.

- MLton 20171211 (git 79d4a623c)
- ML Kit 4.3.12 (20171210)
- Moscow ML 2.10.1 ++ (git f529b33bb, 20170711)
- Poly/ML 5.7.2 Testing (git 5.7.1-35-gcb73407a)
- SML/NJ 110.81 (20170501)

There are tables for run time, code size, and compile time.

Setup

All benchmarks were compiled and run on a 2.6 GHz Core i7-5600U with 16G of RAM. The benchmarks were compiled with the default settings for all the compilers, except for Moscow ML, which was passed the `-orthodox -standalone -toplevel` switches. The Poly/ML executables were produced using `polyc`. The SML/NJ executables were produced by wrapping the entire program in a `local` declaration whose body performs an `SMLofNJ.exportFn`.

For more details, or if you want to run the benchmarks yourself, please see the `benchmark` directory of our Sources.

All of the benchmarks are available for download from this page. Some of the benchmarks were obtained from the SML/NJ benchmark suite. Some of the benchmarks expect certain input files to exist in the `DATA` subdirectory.

- `hamlet.sml` `hamlet-input.sml`
- `ray.sml` `ray`
- `raytrace.sml` `chess.gml`
- `vliw.sml` `ndotprod.s`

Run-time ratio

The following table gives the ratio of the run time of each benchmark when compiled by another compiler to the run time when compiled by MLton. That is, the larger the number, the slower the generated code runs. A number larger than one indicates that the corresponding compiler produces code that runs more slowly than MLton. A * in an entry means the compiler failed to compile the benchmark or that the benchmark failed to run.

benchmark	MLton	ML-Kit	MosML	Poly/ML	SML/NJ
barnes-hut.sml	1.00	10.11	19.36	2.98	1.24
boyer.sml	1.00	*	7.87	1.22	1.75
checksum.sml	1.00	30.79	*	10.94	9.08
count-graphs.sml	1.00	6.51	40.42	2.34	2.32
DLXSimulator.sml	1.00	0.97	*	0.60	*
even-odd.sml	1.00	0.50	11.50	0.42	0.42
fft.sml	1.00	7.35	81.51	4.03	1.19
fib.sml	1.00	1.41	10.94	1.25	1.17
flat-array.sml	1.00	7.19	68.33	5.28	13.16
hamlet.sml	1.00	4.97	22.85	1.58	*
imp-for.sml	1.00	4.99	57.84	3.34	4.67
knuth-bendix.sml	1.00	*	18.43	3.18	3.06

benchmark	MLton	ML-Kit	MosML	Poly/ML	SML/NJ
lexgen.sml	1.00	2.76	7.94	3.19	*
life.sml	1.00	1.80	20.19	0.89	1.50
logic.sml	1.00	5.10	11.06	1.15	1.27
mandelbrot.sml	1.00	3.50	25.52	1.33	1.28
matrix-multiply.sml	1.00	29.40	183.02	7.41	15.19
md5.sml	1.00	95.18	*	32.61	47.47
merge.sml	1.00	1.42	*	0.74	3.24
mlyacc.sml	1.00	1.83	8.45	0.84	*
model-elimination.sml	1.00	4.03	12.42	1.70	2.25
mpuz.sml	1.00	3.73	57.44	2.05	3.22
nucleic.sml	1.00	3.96	*	1.73	1.20
output1.sml	1.00	6.26	30.85	7.82	5.99
peek.sml	1.00	9.37	44.78	2.18	2.15
psdes-random.sml	1.00	*	*	2.79	3.59
ratio-regions.sml	1.00	5.68	165.56	3.92	37.52
ray.sml	1.00	12.05	25.08	8.73	1.75
raytrace.sml	1.00	*	*	2.11	3.33
simple.sml	1.00	2.95	24.03	3.67	1.93
smith-normal-form.sml	1.00	*	*	1.04	*
string-concat.sml	1.00	1.88	28.01	0.70	2.67
tailfib.sml	1.00	1.58	23.57	0.90	1.04
tak.sml	1.00	1.69	15.90	1.57	2.01
tensor.sml	1.00	*	*	*	2.07
tsp.sml	1.00	2.19	66.76	3.27	1.48
tyan.sml	1.00	*	19.43	1.08	1.03
vector32-concat.sml	1.00	13.85	*	1.80	12.48
vector64-concat.sml	1.00	*	*	*	13.92
vector-rev.sml	1.00	7.88	68.85	9.39	68.80
vliw.sml	1.00	2.46	15.39	1.43	1.55
wc-input1.sml	1.00	6.00	*	29.25	9.54
wc-scanStream.sml	1.00	80.43	*	19.45	8.71
zebra.sml	1.00	4.62	35.56	1.68	9.97
zern.sml	1.00	*	*	*	1.60

Note: for SML/NJ, the `smith-normal-form.sml` benchmark was killed after running for over 51,000 seconds.

Code size

The following table gives the code size of each benchmark in bytes. The size for MLton and the ML Kit is the sum of text and data for the standalone executable as reported by `size`. The size for Moscow ML is the size in bytes of the executable `a.out`. The size for Poly/ML is the difference in size of the database before the session start and after the commit. The size for SML/NJ is the size of the heap file created by `exportFn` and does not include the size of the SML/NJ runtime system (approximately 100K). A * in an entry means that the compiler failed to compile the benchmark.

benchmark	MLton	ML-Kit	MosML	Poly/ML	SML/NJ
barnes-hut.sml	180,788	810,267	199,503	148,120	402,480
boyer.sml	250,246	*	248,018	196,984	496,664
checksum.sml	122,422	225,274	*	106,088	406,560
count-graphs.sml	151,878	250,126	187,048	144,032	428,136
DLXSimulator.sml	223,073	827,483	*	272,664	*
even-odd.sml	122,350	87,586	181,415	106,072	380,928
fft.sml	145,008	237,230	186,228	131,400	418,896

benchmark	MLton	ML-Kit	MosML	Poly/ML	SML/NJ
fib.sml	122,310	87,402	181,312	106,088	380,928
flat-array.sml	121,958	104,102	181,464	106,072	394,256
hamlet.sml	1,503,849	2,280,691	407,219	2,249,504	*
imp-for.sml	122,078	89,346	181,470	106,088	381,952
knuth-bendix.sml	193,145	*	192,659	161,080	400,408
lexgen.sml	308,296	826,819	213,128	268,272	*
life.sml	141,862	721,419	186,463	118,552	384,024
logic.sml	211,086	782,667	188,908	198,408	409,624
mandelbrot.sml	122,086	700,075	183,037	106,104	386,048
matrix-multiply.sml	124,398	280,006	184,328	110,232	416,784
md5.sml	150,497	271,794	*	122,624	399,416
merge.sml	123,846	100,858	181,542	106,136	381,960
mlyacc.sml	678,920	1,233,587	263,721	576,728	*
model-elimination.sml	846,779	1,432,283	297,108	777,664	985,304
mpuz.sml	124,126	229,078	184,440	114,584	392,232
nucleic.sml	298,038	507,186	*	475,808	456,744
output1.sml	157,973	699,003	181,680	118,800	380,928
peek.sml	156,401	201,138	183,438	110,456	385,072
psdes-random.sml	126,486	106,166	*	106,088	393,256
ratio-regions.sml	150,174	265,694	190,088	184,536	414,760
ray.sml	260,863	736,795	195,064	198,976	512,160
raytrace.sml	384,905	*	*	446,424	623,824
simple.sml	365,578	895,139	197,765	1,051,952	708,696
smith-normal-form.sml	286,474	*	*	262,616	547,984
string-concat.sml	119,102	140,626	183,249	106,088	390,160
tailfib.sml	122,110	87,890	181,369	106,072	381,952
tak.sml	122,246	87,402	181,349	106,088	376,832
tensor.sml	186,545	*	*	*	421,984
tsp.sml	163,033	722,571	188,634	126,984	393,264
tyan.sml	235,449	*	195,401	184,816	478,296
vector32-concat.sml	123,790	104,398	*	106,200	394,256
vector64-concat.sml	123,846	*	*	*	405,552
vector-rev.sml	122,982	104,614	181,534	106,072	394,256
vliw.sml	538,074	1,182,851	249,884	580,792	749,752
wc-input1.sml	186,152	699,459	191,347	127,200	386,048
wc-scanStream.sml	196,232	700,131	191,539	127,232	387,072
zebra.sml	230,433	128,354	186,322	127,048	390,184
zern.sml	156,902	*	*	*	453,768

Compile time

The following table gives the compile time of each benchmark in seconds. A * in an entry means that the compiler failed to compile the benchmark.

benchmark	MLton	ML-Kit	MosML	Poly/ML	SML/NJ
barnes-hut.sml	2.70	0.89	0.15	0.29	0.20
boyer.sml	2.87	*	0.14	0.20	0.41
checksum.sml	2.21	0.24	*	0.07	0.05
count-graphs.sml	2.28	0.34	0.04	0.11	0.21
DLXSimulator.sml	2.93	1.01	*	0.27	*
even-odd.sml	2.23	0.20	0.01	0.07	0.04
fft.sml	2.35	0.28	0.03	0.09	0.10
fib.sml	2.16	0.19	0.01	0.07	0.04

benchmark	MLton	ML-Kit	MosML	Poly/ML	SML/NJ
flat-array.sml	2.16	0.20	0.01	0.07	0.04
hamlet.sml	12.28	19.25	23.75	6.44	*
imp-for.sml	2.14	0.20	0.01	0.08	0.04
knuth-bendix.sml	2.48	*	0.08	0.14	0.23
lexgen.sml	3.31	0.75	0.15	0.22	*
life.sml	2.25	0.32	0.03	0.09	0.10
logic.sml	2.72	0.57	0.07	0.17	0.21
mandelbrot.sml	2.14	0.24	0.01	0.07	0.04
matrix-multiply.sml	2.14	0.24	0.01	0.08	0.05
md5.sml	2.31	0.39	*	0.12	0.27
merge.sml	2.15	0.21	0.01	0.07	0.04
mlyacc.sml	7.07	4.53	2.05	0.80	*
model-elimination.sml	6.78	4.76	1.20	1.65	4.78
mpuz.sml	2.14	0.28	0.02	0.08	0.07
nucleic.sml	3.96	2.12	*	0.37	0.49
output1.sml	2.30	0.22	0.01	0.07	0.04
peek.sml	2.26	0.20	0.01	0.07	0.04
psdes-random.sml	2.12	0.22	*	9.83	12.55
ratio-regions.sml	2.59	0.47	0.07	0.16	0.24
ray.sml	2.95	0.46	0.05	0.17	0.14
raytrace.sml	3.93	*	*	0.45	0.74
simple.sml	3.42	1.23	0.30	0.32	0.53
smith-normal-form.sml	3.23	*	*	0.15	0.32
string-concat.sml	2.25	0.28	0.01	0.08	0.05
tailfib.sml	2.24	0.21	0.01	0.08	0.05
tak.sml	2.23	0.20	0.01	0.08	0.05
tensor.sml	2.73	*	*	*	0.44
tsp.sml	2.42	0.38	0.05	0.11	0.11
tyan.sml	2.93	*	0.10	0.27	0.31
vector32-concat.sml	2.23	0.22	*	0.07	0.04
vector64-concat.sml	2.18	*	*	*	0.04
vector-rev.sml	2.23	0.22	0.01	0.08	0.05
vliw.sml	5.25	2.93	0.63	0.94	1.85
wc-input1.sml	2.46	0.24	0.01	0.08	0.05
wc-scanStream.sml	2.61	0.25	0.01	0.08	0.05
zebra.sml	2.99	0.35	0.03	0.09	0.11
zern.sml	2.31	*	*	*	0.11

PhantomType

A phantom type is a type that has no run-time representation, but is used to force the type checker to ensure invariants at compile time. This is done by augmenting a type with additional arguments (phantom type variables) and expressing constraints by choosing phantom types to stand for the phantom types in the types of values.

Also see

- Blume01
  - dimensions
  - C type system
- FluetPucella06
  - subtyping
- socket module in Basis Library

PlatformSpecificNotes

Here are notes about using MLton on the following platforms.

Operating Systems

- AIX
- Cygwin
- Darwin
- FreeBSD
- HPUX
- Linux
- MinGW
- NetBSD
- OpenBSD
- Solaris

Architectures

- AMD64
- HPPA
- PowerPC
- PowerPC64
- Sparc
- X86

Also see

- PortingMLton

PolyEqual

PolyEqual is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

This pass implements polymorphic equality.

Implementation

- poly-equal.fun

Details and Notes

For each datatype, tycon, and vector type, it builds and equality function and translates calls to `MLton_equal` into calls to that function.

Also generates calls to `Word_equal`.

For tuples, it does the equality test inline; i.e., it does not create a separate equality function for each tuple type.

All equality functions are created only if necessary, i.e., if equality is actually used at a type.

Optimizations:

- for datatypes that are enumerations, do not build a case dispatch, just use `MLton_eq`, as the backend will represent these as ints
- deep equality always does an `MLton_eq` test first
- If one argument to = is a constant and the type will get translated to an `IntOrPointer`, then just use `eq` instead of the full equality. This is important for implementing code like the following efficiently:

```
if x = 0  ...    (* where x is of type IntInf.int *)
```

- Also convert pointer equality on scalar types to type specific primitives.

PolyHash

PolyHash is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

This pass implements polymorphic, structural hashing.

Implementation

- `poly-hash.fun`

Details and Notes

For each datatype, tycon, and vector type, it builds and equality function and translates calls to `MLton_hash` into calls to that function.

For tuples, it does the equality test inline; i.e., it does not create a separate equality function for each tuple type.

All equality functions are created only if necessary, i.e., if equality is actually used at a type.

PolyML

Poly/ML is a Standard ML implementation.

Also see

- Matthews95

PolymorphicEquality

Polymorphic equality is a built-in function in Standard ML that compares two values of the same type for equality. It is specified as

```
val = : ''a * ''a -> bool
```

The ''a in the specification are equality type variables, and indicate that polymorphic equality can only be applied to values of an equality type. It is not allowed in SML to rebind =, so a programmer is guaranteed that = always denotes polymorphic equality.

Equality of ground types

Ground types like `char`, `int`, and `word` may be compared (to values of the same type). For example, `13 =14` is type correct and yields `false`.

Equality of reals

The one ground type that can not be compared is `real`. So, `13.0 =14.0` is not type correct. One can use `Real.==` to compare reals for equality, but beware that this has different algebraic properties than polymorphic equality.

See http://standardml.org/Basis/real.html for a discussion of why `real` is not an equality type.

Equality of functions

Comparison of functions is not allowed.

Equality of immutable types

Polymorphic equality can be used on immutable values like tuples, records, lists, and vectors. For example,

```
(1, 2, 3) = (4, 5, 6)
```

is a type-correct expression yielding `false`, while

```
[1, 2, 3] = [1, 2, 3]
```

is type correct and yields `true`.

Equality on immutable values is computed by structure, which means that values are compared by recursively descending the data structure until ground types are reached, at which point the ground types are compared with primitive equality tests (like comparison of characters). So, the expression

```
[1, 2, 3] = [1, 1 + 1, 1 + 1 + 1]
```

is guaranteed to yield `true`, even though the lists may occupy different locations in memory.

Because of structural equality, immutable values can only be compared if their components can be compared. For example, `[1, 2, 3]` can be compared, but `[1.0, 2.0, 3.0]` can not. The SML type system uses equality types to ensure that structural equality is only applied to valid values.

Equality of mutable values

In contrast to immutable values, polymorphic equality of mutable values (like ref cells and arrays) is performed by pointer comparison, not by structure. So, the expression

```
ref 13 = ref 13
```

is guaranteed to yield `false`, even though the ref cells hold the same contents.

Because equality of mutable values is not structural, arrays and refs can be compared *even if their components are not equality types*. Hence, the following expression is type correct (and yields true).

```
let
   val r = ref 13.0
in
   r = r
end
```

Equality of datatypes

Polymorphic equality of datatypes is structural. Two values of the same datatype are equal if they are of the same variant and if the variant's arguments are equal (recursively). So, with the datatype

```
datatype t = A | B of t
```

then `B (B A) =B A` is type correct and yields `false`, while `A =A` and `B A =B A` yield `true`.

As polymorphic equality descends two values to compare them, it uses pointer equality whenever it reaches a mutable value. So, with the datatype

```
datatype t = A of int ref | ...
```

then `A (ref 13) =A (ref 13)` is type correct and yields `false`, because the pointer equality on the two ref cells yields `false`.

One weakness of the SML type system is that datatypes do not inherit the special property of the `ref` and `array` type constructors that allows them to be compared regardless of their component type. For example, after declaring

```
datatype 'a t = A of 'a ref
```

one might expect to be able to compare two values of type `real t`, because pointer comparison on a ref cell would suffice. Unfortunately, the type system can only express that a user-defined datatype admits equality or not. In this case, `t` admits equality, which means that `int t` can be compared but that `real t` can not. We can confirm this with the program

```
datatype 'a t = A of 'a ref
fun f (x: real t, y: real t) = x = y
```

on which MLton reports the following error.

```
Error: z.sml 2.32-2.36.
  Function applied to incorrect argument.
    expects: [<equality>] t * [<equality>] t
    but got: [real] t * [real] t
    in: = (x, y)
```

Implementation

Polymorphic equality is implemented by recursively descending the two values being compared, stopping as soon as they are determined to be unequal, or exploring the entire values to determine that they are equal. Hence, polymorphic equality can take time proportional to the size of the smaller value.

MLton uses some optimizations to improve performance.

- When computing structural equality, first do a pointer comparison. If the comparison yields `true`, then stop and return `true`, since the structural comparison is guaranteed to do so. If the pointer comparison fails, then recursively descend the values.
- If a datatype is an enum (e.g. `datatype t =A | B | C`), then a single comparison suffices to compare values of the datatype. No case dispatch is required to determine whether the two values are of the same variant.
- When comparing a known constant non-value-carrying variant, use a single comparison. For example, the following code will compile into a single comparison for `A =x`.

```
datatype t = A | B | C of ...
fun f x = ... if A = x then ...
```

- When comparing a small constant `IntInf.int` to another `IntInf.int`, use a single comparison against the constant. No case dispatch is required.

Also see

- AdmitsEquality
- EqualityType
- EqualityTypeVariable

Polyvariance

Polyvariance is an optimization pass for the SXML IntermediateLanguage, invoked from SXMLSimplify.

Description

This pass duplicates a higher-order, `let` bound function at each variable reference, if the cost is smaller than some threshold.

Implementation

- `polyvariance.fun`

Details and Notes

Poplog

POPLOG is a development environment that includes implementations of a number of languages, including Standard ML.

While POPLOG is actively developed, the ML support predates SML'97, and there is no support for the Basis Library specification.

Also see

- Mixed-language programming in ML and Pop-11.

PortingMLton

Porting MLton to a new target platform (architecture or OS) involves the following steps.

1. Make the necessary changes to the scripts, runtime system, Basis Library implementation, and compiler.
2. Get the regressions working using a cross compiler.
3. Cross compile MLton and bootstrap on the target.

MLton has a native code generator only for AMD64 and X86, so, if you are porting to another architecture, you must use the C code generator. These notes do not cover building a new native code generator.

Some of the following steps will not be necessary if MLton already supports the architecture or operating system you are porting to.

What code to change

- Scripts.
  - In `bin/platform`, add new cases to define `$HOST_OS` and `$HOST_ARCH`.
- Runtime system.

  The goal of this step is to be able to successfully run `make` in the `runtime` directory on the target machine.
  - In `platform.h`, add a new case to include `platform/<arch>.h` and `platform/<os>.h`.
  - In `platform/<arch>.h`:
    * define `MLton_Platform_Arch_host`.
  - In `platform/<os>.h`:
    * include platform-specific includes.
    * define `MLton_Platform_OS_host`.
    * define all of the `HAS_*` macros.
  - In `platform/<os>.c` implement any platform-dependent functions that the runtime needs.
  - Add rounding mode control to `basis/Real/IEEEReal.c` for the new arch (if not `HAS_FEROUND`)
  - Compile and install the GnuMP. This varies from platform to platform. In `platform/<os>.h`, you need to include the appropriate `gmp.h`.
- Basis Library implementation (`basis-library/*`)
  - In `primitive/prim-mlton.sml`:
    * Add a new variant to the `MLton.Platform.Arch.t` datatype.
    * modify the constants that define `MLton.Platform.Arch.host` to match with `MLton_Platform_Arch_host`, as set in `runtime/platform/<arch>.h`.
    * Add a new variant to the `MLton.Platform.OS.t` datatype.
    * modify the constants that define `MLton.Platform.OS.host` to match with `MLton_Platform_OS_host`, as set in `runtime/platform/<os>.h`.
  - In `mlton/platform.{sig,sml}` add a new variant.
  - In `sml-nj/sml-nj.sml`, modify `getOSKind`.
  - Look at all the uses of `MLton.Platform` in the Basis Library implementation and see if you need to do anything special. You might use the following command to see where to look.

    ```
    find basis-library -type f | xargs grep 'MLton\.Platform'
    ```

    If in doubt, leave the code alone and wait to see what happens when you run the regression tests.

- Compiler.
  - In `lib/stubs/mlton-stubs/platform.sig` add any new variants, as was done in the Basis Library.
  - In `lib/stubs/mlton-stubs/mlton.sml` add any new variants in `MLton.Platform`, as was done in the Basis Library.

The string used to identify a particular architecture or operating system must be the same (except for possibly case of letters) in the scripts, runtime, Basis Library implementation, and compiler (stubs). In `mlton/main/main.fun`, MLton itself uses the conversions to and from strings:

```
MLton.Platform.{Arch,OS}.{from,to}String
```

If the there is a mismatch, you may see the error message `strange arch` or `strange os`.

Running the regressions with a cross compiler

When porting to a new platform, it is always best to get all (or as many as possible) of the regressions working before moving to a self compile. It is easiest to do this by modifying and rebuilding the compiler on a working machine and then running the regressions with a cross compiler. It is not easy to build a gcc cross compiler, so we recommend generating the C and assembly on a working machine (using MLton's `-target` and `-stop g` flags, copying the generated files to the target machine, then compiling and linking there.

1. Remake the compiler on a working machine.
2. Use `bin/add-cross` to add support for the new target. In particular, this should create `build/lib/mlton/targets/<target>/` with the platform-specific necessary cross-compilation information.
3. Run the regression tests with the cross-compiler. To cross-compile all the tests, do

   ```
   bin/regression -cross <target>
   ```

   This will create all the executables. Then, copy `bin/regression` and the `regression` directory to the target machine, and do

   ```
   bin/regression -run-only <target>
   ```

   This should run all the tests.

Repeat this step, interleaved with appropriate compiler modifications, until all the regressions pass.

Bootstrap

Once you've got all the regressions working, you can build MLton for the new target. As with the regressions, the idea for bootstrapping is to generate the C and assembly on a working machine, copy it to the target machine, and then compile and link there. Here's the sequence of steps.

1. On a working machine, with the newly rebuilt compiler, in the `mlton` directory, do:

   ```
   mlton -stop g -target <target> mlton.mlb
   ```

2. Copy to the target machine.
3. On the target machine, move the libraries to the right place. That is, in `build/lib/mlton/targets`, do:

   ```
   rm -rf self
   mv <target> self
   ```

Also make sure you have all the header files in build/lib/mlton/include. You can copy them from a host machine that has run `make runtime`.

4. On the target machine, compile and link MLton. That is, in the mlton directory, do something like:

```
gcc -c -Ibuild/lib/mlton/include -Ibuild/lib/mlton/targets/self/include -O1 -w mlton/ ←
    mlton.*.[cs]
gcc -o build/lib/mlton/mlton-compile \
        -Lbuild/lib/mlton/targets/self \
        -L/usr/local/lib \
        mlton.*.o \
        -lmlton -lgmp -lgdtoa -lm
```

5. At this point, MLton should be working and you can finish the rest of a usual make on the target machine.

```
make basis-no-check script mlbpathmap constants libraries tools
```

6. Making the last tool, mlyacc, will fail, because mlyacc cannot bootstrap its own yacc.grm.* files. On the host machine, run `make -C mlyacc src/yacc.grm.sml`. Then copy both files to the target machine, and compile mlyacc, making sure to supply the path to your newly compile mllex: `make -C mlyacc MLLEX=mllex/mllex`.

There are other details to get right, like making sure that the tools directories were clean so that the tools are rebuilt on the new platform, but hopefully this structure works. Once you've got a compiler on the target machine, you should test it by running all the regressions normally (i.e. without the `-cross` flag) and by running a couple rounds of self compiles.

Also see

The above description is based on the following emails sent to the MLton list.

- http://www.mlton.org/pipermail/mlton/2002-October/013110.html
- http://www.mlton.org/pipermail/mlton/2004-July/016029.html

PrecedenceParse

PrecedenceParse is an analysis/rewrite pass for the AST IntermediateLanguage, invoked from Elaborate.

Description

This pass rewrites AST function clauses, expressions, and patterns to resolve OperatorPrecedence.

Implementation

- `precedence-parse.sig`
- `precedence-parse.fun`

Details and Notes

Printf

Programmers coming from C or Java often ask if Standard ML has a `printf` function. It does not. However, it is possible to implement your own version with only a few lines of code.

Here is a definition for `printf` and `fprintf`, along with format specifiers for booleans, integers, and reals.

```
structure Printf =
   struct
      fun $ (_, f) = f (fn p => p ()) ignore
      fun fprintf out f = f (out, id)
      val printf = fn z => fprintf TextIO.stdOut z
      fun one ((out, f), make) g =
         g (out, fn r =>
            f (fn p =>
               make (fn s =>
                     r (fn () => (p (); TextIO.output (out, s))))))
      fun ` x s = one (x, fn f => f s)
      fun spec to x = one (x, fn f => f o to)
      val B = fn z => spec Bool.toString z
      val I = fn z => spec Int.toString z
      val R = fn z => spec Real.toString z
   end
```

Here's an example use.

```
val () = printf `"Int="I`"  Bool="B`"  Real="R`"\n" $ 1 false 2.0
```

This prints the following.

```
Int=1  Bool=false  Real=2.0
```

In general, a use of `printf` looks like

```
printf <spec1> ... <specn> $ <arg1> ... <argm>
```

where each `<speci>` is either a specifier like `B`, `I`, or `R`, or is an inline string, like `` `"foo" ``. A backtick (`` ` ``) must precede each inline string. Each `<argi>` must be of the appropriate type for the corresponding specifier.

SML `printf` is more powerful than its C counterpart in a number of ways. In particular, the function produced by `printf` is a perfectly ordinary SML function, and can be passed around, used multiple times, etc. For example:

```
val f: int -> bool -> unit = printf `"Int="I`"  Bool="B`"\n" $
val () = f 1 true
val () = f 2 false
```

The definition of `printf` is even careful to not print anything until it is fully applied. So, examples like the following will work as expected.

```
val f: int -> bool -> unit = printf `"Int="I`"  Bool="B`"\n" $ 13
val () = f true
val () = f false
```

It is also easy to define new format specifiers. For example, suppose we wanted format specifiers for characters and strings.

```
val C = fn z => spec Char.toString z
val S = fn z => spec (fn s => s) z
```

One can define format specifiers for more complex types, e.g. pairs of integers.

```
val I2 =
   fn z =>
   spec (fn (i, j) =>
         concat ["(", Int.toString i, ", ", Int.toString j, ")"])
   z
```

Here's an example use.

```
val () = printf `"Test "I2`"  a string "S`"\n" $ (1, 2) "hello"
```

Printf via Fold

`printf` is best viewed as a special case of variable-argument Fold that inductively builds a function as it processes its arguments. Here is the definition of a `Printf` structure in terms of fold. The structure is equivalent to the above one, except that it uses the standard `$` instead of a specialized one.

```
structure Printf =
   struct
      fun fprintf out =
         Fold.fold ((out, id), fn (_, f) => f (fn p => p ()) ignore)

      val printf = fn z => fprintf TextIO.stdOut z

      fun one ((out, f), make) =
         (out, fn r =>
          f (fn p =>
             make (fn s =>
                   r (fn () => (p (); TextIO.output (out, s))))))

      val ` =
         fn z => Fold.step1 (fn (s, x) => one (x, fn f => f s)) z

      fun spec to = Fold.step0 (fn x => one (x, fn f => f o to))

      val B = fn z => spec Bool.toString z
      val I = fn z => spec Int.toString z
      val R = fn z => spec Real.toString z
   end
```

Viewing `printf` as a fold opens up a number of possibilities. For example, one can name parts of format strings using the fold idiom for naming sequences of steps.

```
val IB = fn u => Fold.fold u `"Int="I`" Bool="B
val () = printf IB`"  "IB`"\n" $ 1 true 3 false
```

One can even parametrize over partial format strings.

```
fun XB X = fn u => Fold.fold u `"X="X`" Bool="B
val () = printf (XB I)`"  "(XB R)`"\n" $ 1 true 2.0 false
```

Also see

- PrintfGentle
- Functional Unparsing

PrintfGentle

This page provides a gentle introduction and derivation of Printf, with sections and arrangement more suitable to a talk.

Introduction

SML does not have `printf`. Could we define it ourselves?

```
val () = printf ("here's an int %d and a real %f.\n", 13, 17.0)
val () = printf ("here's three values (%d, %f, %f).\n", 13, 17.0, 19.0)
```

What could the type of `printf` be?

This obviously can't work, because SML functions take a fixed number of arguments. Actually they take one argument, but if that's a tuple, it can only have a fixed number of components.

From tupling to currying

What about currying to get around the typing problem?

```
val () = printf "here's an int %d and a real %f.\n" 13 17.0
val () = printf "here's three values (%d, %f, %f).\n" 13 17.0 19.0
```

That fails for a similar reason. We need two types for `printf`.

```
val printf: string -> int -> real -> unit
val printf: string -> int -> real -> real -> unit
```

This can't work, because `printf` can only have one type. SML doesn't support programmer-defined overloading.

Overloading and dependent types

Even without worrying about number of arguments, there is another problem. The type of `printf` depends on the format string.

```
val () = printf "here's an int %d and a real %f.\n" 13 17.0
val () = printf "here's a real %f and an int %d.\n" 17.0 13
```

Now we need

```
val printf: string -> int -> real -> unit
val printf: string -> real -> int -> unit
```

Again, this can't possibly working because SML doesn't have overloading, and types can't depend on values.

Idea: express type information in the format string

If we express type information in the format string, then different uses of `printf` can have different types.

```
type 'a t  (* the type of format strings *)
val printf: 'a t -> 'a
infix D F
val fs1: (int -> real -> unit) t = "here's an int "D" and a real "F".\n"
val fs2: (int -> real -> real -> unit) t =
   "here's three values ("D", "F", "F").\n"
val () = printf fs1 13 17.0
val () = printf fs2 13 17.0 19.0
```

Now, our two calls to `printf` type check, because the format string specializes `printf` to the appropriate type.

The types of format characters

What should the type of format characters `D` and `F` be? Each format character requires an additional argument of the appropriate type to be supplied to `printf`.

Idea: guess the final type that will be needed for `printf` the format string and verify it with each format character.

```
type ('a, 'b) t   (* 'a = rest of type to verify, 'b = final type *)
val ` : string -> ('a, 'a) t  (* guess the type, which must be verified *)
val D: (int -> 'a, 'b) t * string -> ('a, 'b) t  (* consume an int *)
val F: (real -> 'a, 'b) t * string -> ('a, 'b) t  (* consume a real *)
val printf: (unit, 'a) t -> 'a
```

Don't worry. In the end, type inference will guess and verify for us.

Understanding guess and verify

Now, let's build up a format string and a specialized `printf`.

```
infix D F
val f0 = `"here's an int "
val f1 = f0 D " and a real "
val f2 = f1 F ".\n"
val p = printf f2
```

These definitions yield the following types.

```
val f0: (int -> real -> unit, int -> real -> unit) t
val f1: (real -> unit, int -> real -> unit) t
val f2: (unit, int -> real -> unit) t
val p: int -> real -> unit
```

So, `p` is a specialized `printf` function. We could use it as follows

```
val () = p 13 17.0
val () = p 14 19.0
```

Type checking this using a functor

```
signature PRINTF =
   sig
      type ('a, 'b) t
      val ` : string -> ('a, 'a) t
      val D: (int -> 'a, 'b) t * string -> ('a, 'b) t
      val F: (real -> 'a, 'b) t * string -> ('a, 'b) t
      val printf: (unit, 'a) t -> 'a
   end

functor Test (P: PRINTF) =
   struct
      open P
      infix D F

      val () = printf (`"here's an int "D" and a real "F".\n") 13 17.0
      val () = printf (`"here's three values ("D", "F ", "F").\n") 13 17.0 19.0
   end
```

Implementing Printf

Think of a format character as a formatter transformer. It takes the formatter for the part of the format string before it and transforms it into a new formatter that first does the left hand bit, then does its bit, then continues on with the rest of the format string.

```
structure Printf: PRINTF =
   struct
      datatype ('a, 'b) t = T of (unit -> 'a) -> 'b

      fun printf (T f) = f (fn () => ())

      fun ` s = T (fn a => (print s; a ()))

      fun D (T f, s) =
         T (fn g => f (fn () => fn i =>
                          (print (Int.toString i); print s; g ())))

      fun F (T f, s) =
         T (fn g => f (fn () => fn i =>
                          (print (Real.toString i); print s; g ())))
   end
```

Testing printf

```
structure Z = Test (Printf)
```

User-definable formats

The definition of the format characters is pretty much the same. Within the `Printf` structure we can define a format character generator.

```
val newFormat: ('a -> string) -> ('a -> 'b, 'c) t * string -> ('b, 'c) t =
   fn toString => fn (T f, s) =>
   T (fn th => f (fn () => fn a => (print (toString a); print s ; th ())))
val D = fn z => newFormat Int.toString z
val F = fn z => newFormat Real.toString z
```

A core Printf

We can now have a very small `PRINTF` signature, and define all the format strings externally to the core module.

```
signature PRINTF =
   sig
      type ('a, 'b) t
      val ` : string -> ('a, 'a) t
      val newFormat: ('a -> string) -> ('a -> 'b, 'c) t * string -> ('b, 'c) t
      val printf: (unit, 'a) t -> 'a
   end

structure Printf: PRINTF =
   struct
      datatype ('a, 'b) t = T of (unit -> 'a) -> 'b

      fun printf (T f) = f (fn () => ())
```

```
      fun ` s = T (fn a => (print s; a ()))

      fun newFormat toString (T f, s) =
         T (fn th =>
            f (fn () => fn a =>
               (print (toString a)
                ; print s
                ; th ())))
   end
```

Extending to fprintf

One can implement fprintf by threading the outstream through all the transformers.

```
signature PRINTF =
   sig
      type ('a, 'b) t
      val ` : string -> ('a, 'a) t
      val fprintf: (unit, 'a) t * TextIO.outstream -> 'a
      val newFormat: ('a -> string) -> ('a -> 'b, 'c) t * string -> ('b, 'c) t
      val printf: (unit, 'a) t -> 'a
   end

structure Printf: PRINTF =
   struct
      type out = TextIO.outstream
      val output = TextIO.output

      datatype ('a, 'b) t = T of (out -> 'a) -> out -> 'b

      fun fprintf (T f, out) = f (fn _ => ()) out

      fun printf t = fprintf (t, TextIO.stdOut)

      fun ` s = T (fn a => fn out => (output (out, s); a out))

      fun newFormat toString (T f, s) =
         T (fn g =>
            f (fn out => fn a =>
               (output (out, toString a)
                ; output (out, s)
                ; g out)))
   end
```

Notes

- Lesson: instead of using dependent types for a function, express the the dependency in the type of the argument.
- If `printf` is partially applied, it will do the printing then and there. Perhaps this could be fixed with some kind of terminator.

  A syntactic or argument terminator is not necessary. A formatter can either be eager (as above) or lazy (as below). A lazy formatter accumulates enough state to print the entire string. The simplest lazy formatter concatenates the strings as they become available:

```
structure PrintfLazyConcat: PRINTF =
   struct
      datatype ('a, 'b) t = T of (string -> 'a) -> string -> 'b

      fun printf (T f) = f print ""
```

```
      fun ` s = T (fn th => fn s' => th (s' ^ s))

      fun newFormat toString (T f, s) =
         T (fn th =>
            f (fn s' => fn a =>
               th (s' ^ toString a ^ s)))
   end
```

It is somewhat more efficient to accumulate the strings as a list:

```
structure PrintfLazyList: PRINTF =
   struct
      datatype ('a, 'b) t = T of (string list -> 'a) -> string list -> 'b

      fun printf (T f) = f (List.app print o List.rev) []

      fun ` s = T (fn th => fn ss => th (s::ss))

      fun newFormat toString (T f, s) =
         T (fn th =>
            f (fn ss => fn a =>
               th (s::toString a::ss)))
   end
```

Also see

- Printf
- Functional Unparsing

ProductType

Standard ML has special syntax for products (tuples). A product type is written as

```
t1 * t2 * ... * tN
```

and a product pattern is written as

```
(p1, p2, ..., pN)
```

In most situations the syntax is quite convenient. However, there are situations where the syntax is cumbersome. There are also situations in which it is useful to construct and destruct n-ary products inductively, especially when using Fold.

In such situations, it is useful to have a binary product datatype with an infix constructor defined as follows.

```
datatype ('a, 'b) product = & of 'a * 'b
infix &
```

With these definitions, one can write an n-ary product as a nested binary product quite conveniently.

```
x1 & x2 & ... & xn
```

Because of left associativity, this is the same as

```
(((x1 & x2) & ...) & xn)
```

Because `&` is a constructor, the syntax can also be used for patterns.

The symbol `&` is inspired by the Curry-Howard isomorphism: the proof of a conjunction `(A & B)` is a pair of proofs `(a, b)`.

Example: parser combinators

A typical parser combinator library provides a combinator that has a type of the form.

```
'a parser * 'b parser -> ('a * 'b) parser
```

and produces a parser for the concatenation of two parsers. When more than two parsers are concatenated, the result of the resulting parser is a nested structure of pairs

```
(...((p1, p2), p3)..., pN)
```

which is somewhat cumbersome.

By using a product type, the type of the concatenation combinator then becomes

```
'a parser * 'b parser -> ('a, 'b) product parser
```

While this doesn't stop the nesting, it makes the pattern significantly easier to write. Instead of

```
(...((p1, p2), p3)..., pN)
```

the pattern is written as

```
p1 & p2 & p3 & ... & pN
```

which is considerably more concise.

Also see

- VariableArityPolymorphism
- Utilities

Profiling

With MLton and `mlprof`, you can profile your program to find out bytes allocated, execution counts, or time spent in each function. To profile you program, compile with `-profile kind`, where *kind* is one of `alloc`, `count`, or `time`. Then, run the executable, which will write an `mlmon.out` file when it finishes. You can then run `mlprof` on the executable and the `mlmon.out` file to see the performance data.

Here are the three kinds of profiling that MLton supports.

- ProfilingAllocation
- ProfilingCounts
- ProfilingTime

Next steps

- CallGraphs to visualize profiling data.
- HowProfilingWorks
- MLmon
- MLtonProfile to selectively profile parts of your program.
- ProfilingTheStack
- ShowProf

ProfilingAllocation

With MLton and `mlprof`, you can profile your program to find out how many bytes each function allocates. To do so, compile your program with `-profile alloc`. For example, suppose that `list-rev.sml` is the following.

```
fun append (l1, l2) =
   case l1 of
      [] => l2
    | x :: l1 => x :: append (l1, l2)

fun rev l =
   case l of
      [] => []
    | x :: l => append (rev l, [x])

val l = List.tabulate (1000, fn i => i)
val _ = 1 + hd (rev l)
```

Compile and run `list-rev` as follows.

```
% mlton -profile alloc list-rev.sml
% ./list-rev
% mlprof -show-line true list-rev mlmon.out
6,030,136 bytes allocated (108,336 bytes by GC)
       function          cur
----------------------- -----
append  list-rev.sml: 1 97.6%
<gc>                     1.8%
<main>                   0.4%
rev  list-rev.sml: 6     0.2%
```

The data shows that most of the allocation is done by the `append` function defined on line 1 of `list-rev.sml`. The table also shows how special functions like `gc` and `main` are handled: they are printed with surrounding brackets. C functions are displayed similarly. In this example, the allocation done by the garbage collector is due to stack growth, which is usually the case.

The run-time performance impact of allocation profiling is noticeable, because it inserts additional C calls for object allocation.

Compile with `-profile alloc -profile-branch true` to find out how much allocation is done in each branch of a function; see ProfilingCounts for more details on `-profile-branch`.

ProfilingCounts

With MLton and `mlprof`, you can profile your program to find out how many times each function is called and how many times each branch is taken. To do so, compile your program with `-profile count -profile-branch true`. For example, suppose that `tak.sml` contains the following.

```
structure Tak =
   struct
      fun tak1 (x, y, z) =
         let
            fun tak2 (x, y, z) =
               if y >= x
                  then z
               else
                  tak1 (tak2 (x - 1, y, z),
                        tak2 (y - 1, z, x),
                        tak2 (z - 1, x, y))
         in
            if y >= x
               then z
            else
               tak1 (tak2 (x - 1, y, z),
                     tak2 (y - 1, z, x),
                     tak2 (z - 1, x, y))
         end
   end

val rec f =
   fn 0 => ()
    | ~1 => print "this branch is not taken\n"
    | n => (Tak.tak1 (18, 12, 6) ; f (n-1))

val _ = f 5000

fun uncalled () = ()
```

Compile with count profiling and run the program.

```
% mlton -profile count -profile-branch true tak.sml
% ./tak
```

Display the profiling data, along with raw counts and file positions.

```
% mlprof -raw true -show-line true tak mlmon.out
623,610,002 ticks
            function                   cur       raw
--------------------------------- ----- -------------
Tak.tak1.tak2  tak.sml: 5          38.2% (238,530,000)
Tak.tak1.tak2.<true>  tak.sml: 7  27.5% (171,510,000)
Tak.tak1  tak.sml: 3               10.7%  (67,025,000)
Tak.tak1.<true>  tak.sml: 14       10.7%  (67,025,000)
Tak.tak1.tak2.<false>  tak.sml: 9 10.7%  (67,020,000)
Tak.tak1.<false>  tak.sml: 16      2.0%  (12,490,000)
f  tak.sml: 23                      0.0%       (5,001)
f.<branch>  tak.sml: 25             0.0%       (5,000)
f.<branch>  tak.sml: 23             0.0%           (1)
uncalled  tak.sml: 29               0.0%           (0)
f.<branch>  tak.sml: 24             0.0%           (0)
```

Branches are displayed with lexical nesting followed by `<branch>` where the function name would normally be, or `<true>` or `<false>` for if-expressions. It is best to run `mlprof` with `-show-line true` to help identify the branch.

One use of `-profile count` is as a code-coverage tool, to help find code in your program that hasn't been tested. For this reason, `mlprof` displays functions and branches even if they have a count of zero. As the above output shows, the branch on line 24 was never taken and the function defined on line 29 was never called. To see zero counts, it is best to run `mlprof` with `-raw true`, since some code (e.g. the branch on line 23 above) will show up with `0.0%` but may still have been executed and hence have a nonzero raw count.

ProfilingTheStack

For all forms of Profiling, you can gather counts for all functions on the stack, not just the currently executing function. To do so, compile your program with `-profile-stack true`. For example, suppose that `list-rev.sml` contains the following.

```
fun append (l1, l2) =
   case l1 of
      [] => l2
    | x :: l1 => x :: append (l1, l2)

fun rev l =
   case l of
      [] => []
    | x :: l => append (rev l, [x])

val l = List.tabulate (1000, fn i => i)
val _ = 1 + hd (rev l)
```

Compile with stack profiling and then run the program.

```
% mlton -profile alloc -profile-stack true list-rev.sml
% ./list-rev
```

Display the profiling data.

```
% mlprof -show-line true list-rev mlmon.out
6,030,136 bytes allocated (108,336 bytes by GC)
       function          cur  stack  GC
----------------------- ----- ----- ----
append  list-rev.sml: 1 97.6% 97.6% 1.4%
<gc>                     1.8%  0.0% 1.8%
<main>                   0.4% 98.2% 1.8%
rev  list-rev.sml: 6     0.2% 97.6% 1.8%
```

In the above table, we see that `rev`, defined on line 6 of `list-rev.sml`, is only responsible for 0.2% of the allocation, but is on the stack while 97.6% of the allocation is done by the user program and while 1.8% of the allocation is done by the garbage collector.

The run-time performance impact of `-profile-stack true` can be noticeable since there is some extra bookkeeping at every nontail call and return.

ProfilingTime

With MLton and `mlprof`, you can profile your program to find out how much time is spent in each function over an entire run of the program. To do so, compile your program with `-profile time`. For example, suppose that `tak.sml` contains the following.

```
structure Tak =
   struct
      fun tak1 (x, y, z) =
         let
            fun tak2 (x, y, z) =
               if y >= x
                  then z
               else
                  tak1 (tak2 (x - 1, y, z),
                        tak2 (y - 1, z, x),
                        tak2 (z - 1, x, y))
         in
            if y >= x
               then z
            else
               tak1 (tak2 (x - 1, y, z),
                     tak2 (y - 1, z, x),
                     tak2 (z - 1, x, y))
         end
   end

val rec f =
   fn 0 => ()
    | ~1 => print "this branch is not taken\n"
    | n => (Tak.tak1 (18, 12, 6) ; f (n-1))

val _ = f 5000

fun uncalled () = ()
```

Compile with time profiling and run the program.

```
% mlton -profile time tak.sml
% ./tak
```

Display the profiling data.

```
% mlprof tak mlmon.out
6.00 seconds of CPU time (0.00 seconds GC)
function      cur
------------- -----
Tak.tak1.tak2 75.8%
Tak.tak1      24.2%
```

This example shows how `mlprof` indicates lexical nesting: as a sequence of period-separated names indicating the structures and functions in which a function definition is nested. The profiling data shows that roughly three-quarters of the time is spent in the `Tak.tak1.tak2` function, while the rest is spent in `Tak.tak1`.

Display raw counts in addition to percentages with `-raw true`.

```
% mlprof -raw true tak mlmon.out
6.00 seconds of CPU time (0.00 seconds GC)
  function      cur    raw
------------- ----- -------
Tak.tak1.tak2 75.8% (4.55s)
Tak.tak1      24.2% (1.45s)
```

Display the file name and line number for each function in addition to its name with `-show-line true`.

```
% mlprof -show-line true tak mlmon.out
6.00 seconds of CPU time (0.00 seconds GC)
        function           cur
------------------------- -----
Tak.tak1.tak2  tak.sml: 5 75.8%
Tak.tak1  tak.sml: 3      24.2%
```

Time profiling is designed to have a very small performance impact. However, in some cases there will be a run-time performance cost, which may perturb the results. There is more likely to be an impact with `-codegen c` than `-codegen native`.

You can also compile with `-profile time -profile-branch true` to find out how much time is spent in each branch of a function; see ProfilingCounts for more details on `-profile-branch`.

Caveats

With `-profile time`, use of the following in your program will cause a run-time error, since they would interfere with the profiler signal handler.

- `MLton.Itimer.set (MLton.Itimer.Prof, ...)`
- `MLton.Signal.setHandler (MLton.Signal.prof, ...)`

Also, because of the random sampling used to implement `-profile time`, it is best to have a long running program (at least tens of seconds) in order to get reasonable time

Projects

We have lots of ideas for projects to improve MLton, many of which we do not have time to implement, or at least haven't started on yet. Here is a list of some of those improvements, ranging from the easy (1 week) to the difficult (several months). If you have any interest in working on one of these, or some other improvement to MLton not listed here, please send mail to `MLton-devel@mlton.org`.

- Port to new platform: Windows (native, not Cygwin or MinGW), . . .
- Source-level debugger
- Heap profiler
- Interfaces to libraries: OpenGL, Gtk+, D-BUS, . . .
- More libraries written in SML (see `mltonlib`)
- Additional constant types: `structure Real80:REAL`, . . .
- An IDE (possibly integrated with Eclipse)
- Port MLRISC and use for code generation
- Optimizations
  - Improved closure representation
    Right now, MLton's closure conversion algorithm uses a simple flat closure to represent each function.
    * http://www.mlton.org/pipermail/mlton/2003-October/024570.html
    * http://www.mlton.org/pipermail/mlton-user/2007-July/001150.html
    * ShaoAppel94
  - Elimination of array bounds checks in loops
  - Elimination of overflow checks on array index computations
  - Common-subexpression elimination of repeated array subscripts
  - Loop-invariant code motion, especially for tuple selects
  - Partial redundancy elimination
    * http://www.mlton.org/pipermail/mlton/2006-April/028598.html
  - Loop unrolling, especially for small loops
  - Auto-vectorization, for MMX/SSE/3DNow!/AltiVec (see the work done on GCC)
  - Optimize `MLton_eq`: pointer equality is necessarily false when one of the arguments is freshly allocated in the block
- Analyses
  - Uncaught exception analysis

Pronounce

Here is how "MLton" sounds.

"MLton" is pronounced in two syllables, with stress on the first syllable. The first syllable sounds like the word *mill* (as in "steel mill"), the second like the word *tin* (as in "cookie tin").

PropertyList

A property list is a dictionary-like data structure into which properties (name-value pairs) can be inserted and from which properties can be looked up by name. The term comes from the Lisp language, where every symbol has a property list for storing information, and where the names are typically symbols and keys can be any type of value.

Here is an SML signature for property lists such that for any type of value a new property can be dynamically created to manipulate that type of value in a property list.

```
signature PROPERTY_LIST =
   sig
      type t

      val new: unit -> t
      val newProperty: unit -> {add: t * 'a -> unit,
                                peek: t -> 'a option}
   end
```

Here is a functor demonstrating the use of property lists. It first creates a property list, then two new properties (of different types), and adds a value to the list for each property.

```
functor Test (P: PROPERTY_LIST) =
   struct
      val pl = P.new ()

      val {add = addInt: P.t * int -> unit, peek = peekInt} = P.newProperty ()
      val {add = addReal: P.t * real -> unit, peek = peekReal} = P.newProperty ()

      val () = addInt (pl, 13)
      val () = addReal (pl, 17.0)
      val s1 = Int.toString (valOf (peekInt pl))
      val s2 = Real.toString (valOf (peekReal pl))
      val () = print (concat [s1, " ", s2, "\n"])
   end
```

Applied to an appropriate implementation `PROPERTY_LIST`, the `Test` functor will produce the following output.

```
13 17.0
```

Implementation

Because property lists can hold values of any type, their implementation requires a UniversalType. Given that, a property list is simply a list of elements of the universal type. Adding a property adds to the front of the list, and looking up a property scans the list.

```
functor PropertyList (U: UNIVERSAL_TYPE): PROPERTY_LIST =
   struct
      datatype t = T of U.t list ref

      fun new () = T (ref [])

      fun 'a newProperty () =
         let
            val (inject, out) = U.embed ()
            fun add (T r, a: 'a): unit = r := inject a :: (!r)
            fun peek (T r) =
               Option.map (valOf o out) (List.find (isSome o out) (!r))
         in
            {add = add, peek = peek}
         end
   end
```

If `U:UNIVERSAL_TYPE`, then we can test our code as follows.

```
structure Z = Test (PropertyList (U))
```

Of course, a serious implementation of property lists would have to handle duplicate insertions of the same property, as well as the removal of elements in order to avoid space leaks.

Also see

- MLton relies heavily on property lists for attaching information to syntax tree nodes in its intermediate languages. See `property-list.sig` and `property-list.fun`.
- The MLRISCLibrary uses property lists extensively.

Pygments

Pygments is a generic syntax highlighter. Here is a *lexer* for highlighting Standard ML.

- `sml_lexer` — Provides highlighting of keywords, special constants, and (nested) comments.

Install and use

- Checkout all files and install as a Pygments plugin.

```
$ git clone https://github.com/MLton/mlton.git mlton
$ cd mlton/ide/pygments
$ python setup.py install
```

- Invoke `pygmentize` with `-l sml`.

Feedback

Comments and suggestions should be directed to MatthewFluet.

RayRacine

Using SML in some *Semantic Web* stuff. Anyone interested in similar, please contact me. GreyLensman on #sml on IRC or rracine at this domain adelphia with a dot here net.

Current areas of coding.

1. Pretty solid, high performance Rete implementation - base functionality is complete.
2. N3 parser - mostly complete
3. RDF parser based on fxg - not started.
4. Swerve HTTP server - 1/2 done.
5. SPARQL implementation - not started.
6. Persistent engine based on BerkelyDB - not started.
7. Native implementation of Postgresql protocol - underway, ways to go.
8. I also have a small change to the MLton compiler to add `PackWord<N>` - changes compile but needs some more work, clean-up and unit tests.

Reachability

Reachability is a notion dealing with the graph of heap objects maintained at runtime. Nodes in the graph are heap objects and edges correspond to the pointers between heap objects. As the program runs, it allocates new objects (adds nodes to the graph), and those new objects can contain pointers to other objects (new edges in the graph). If the program uses mutable objects (refs or arrays), it can also change edges in the graph.

At any time, the program has access to some finite set of *root* nodes, and can only ever access nodes that are reachable by following edges from these root nodes. Nodes that are *unreachable* can be garbage collected.

Also see

- MLtonFinalizable
- MLtonWeak

Redundant

Redundant is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

The redundant SSA optimization eliminates redundant function and label arguments; an argument of a function or label is redundant if it is always the same as another argument of the same function or label. The analysis finds an equivalence relation on the arguments of a function or label, such that all arguments in an equivalence class are redundant with respect to the other arguments in the equivalence class; the transformation selects one representative of each equivalence class and drops the binding occurrence of non-representative variables and renames use occurrences of the non-representative variables to the representative variable. The analysis finds the equivalence classes via a fixed-point analysis. Each vector of arguments to a function or label is initialized to equivalence classes that equate all arguments of the same type; one could start with an equivalence class that equates all arguments, but arguments of different type cannot be redundant. Variables bound in statements are initialized to singleton equivalence classes. The fixed-point analysis repeatedly refines these equivalence classes on the formals by the equivalence classes of the actuals.

Implementation

- `redundant.fun`

Details and Notes

The reason Redundant got put in was due to some output of the ClosureConvert pass converter where the environment record, or components of it, were passed around in several places. That may have been more relevant with polyvariant analyses (which are long gone). But it still seems possibly relevant, especially with more aggressive flattening, which should reveal some fields in nested closure records that are redundant.

RedundantTests

RedundantTests is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

This pass simplifies conditionals whose results are implied by a previous conditional test.

Implementation

- redundant-tests.fun

Details and Notes

An additional test will sometimes eliminate the overflow test when adding or subtracting 1. In particular, it will eliminate it in the following cases:

```
if x < y
  then ... x + 1 ...
else ... y - 1 ...
```

References

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

A

- An Experimental Analysis of Self-Adjusting Computation Umut Acar, Guy Blelloch, Matthias Blume, and Kanat Tangwongsan. PLDI 2006.
- Compiling with Continuations (addall). ISBN 0521416957. Andrew W. Appel. Cambridge University Press, 1992.
- A Critique of Standard ML. Andrew W. Appel. JFP 1993.
- Modern Compiler Implementation in ML (addall). ISBN 0521582741 Andrew W. Appel. Cambridge University Press, 1998.
- Shrinking Lambda Expressions in Linear Time Andrew Appel and Trevor Jim. JFP 1997.
- A lexical analyzer generator for Standard ML. Version 1.6.0 Andrew W. Appel, James S. Mattson, and David R. Tarditi. 1994

B

- Tree Pattern Matching for ML. Marianne Baudinet, David MacQueen. 1985.

  Describes the match compiler used in an early version of SML/NJ.

- Compiling Standard ML to Java Bytecodes. Nick Benton, Andrew Kennedy, and George Russell. ICFP 1998.
- Interlanguage Working Without Tears: Blending SML with Java. Nick Benton and Andrew Kennedy. ICFP 1999.
- Exceptional Syntax. Nick Benton and Andrew Kennedy. JFP 2001.
- Adventures in Interoperability: The SML.NET Experience. Nick Benton, Andrew Kennedy, and Claudio Russo. PPDP 2004.
- Shrinking Reductions in SML.NET. Nick Benton, Andrew Kennedy, Sam Lindley and Claudio Russo. IFL 2004.

  Describes a linear-time implementation of an Appel-Jim shrinker, using a mutable IL, and shows that it yields nice speedups in SML.NET's compile times. There are also benchmarks showing that SML.NET when compiled by MLton runs roughly five times faster than when compiled by SML/NJ.

- Embedded Interpreters. Nick Benton. JFP 2005.
- The Edinburgh SML Library. Dave Berry. University of Edinburgh Technical Report ECS-LFCS-91-148, 1991.
- A semantics for ML concurrency primitives. Dave Berry, Robin Milner, and David N. Turner. POPL 1992.
- Lessons From the Design of a Standard ML Library. Dave Berry. JFP 1993.
- Compiling SML to Java Bytecode. Peter Bertelsen. Master's Thesis, 1998.
- OO Programming styles in ML. Bernard Berthomieu. LAAS Report #2000111, 2000.
- No-Longer-Foreign: Teaching an ML compiler to speak C "natively". Matthias Blume. BABEL 2001.
- Portable library descriptions for Standard ML. Matthias Blume. 2001.
- Destructors, Finalizers, and Synchronization. Hans Boehm. POPL 2003.

  Discusses a number of issues in the design of finalizers. Many of the design choices are consistent with MLtonFinalizable.

C

- Flow-directed Closure Conversion for Typed Languages. Henry Cejtin, Suresh Jagannathan, and Stephen Weeks. ESOP 2000.

  Describes MLton's closure-conversion algorithm, which translates from its simply-typed higher-order intermediate language to its simply-typed first-order intermediate language.

- A Parallel, Real-Time Garbage Collector. Perry Cheng and Guy E. Blelloch. PLDI 2001.
- QuickCheck: A Lightweight Tool for Random Testing of Haskell Programs. Koen Claessen and John Hughes. ICFP 2000.
- Proper Tail Recursion and Space Efficiency. William D. Clinger. PLDI 1998.
- Adding Threads to Standard ML. Eric C. Cooper and J. Gregory Morrisett. CMU Technical Report CMU-CS-90-186, 1990.
- Stream Fusion: From Lists to Streams to Nothing at All. Duncan Coutts, Roman Leshchinskiy, and Don Stewart. Submitted for publication. April 2007.

D

- Principal Type-Schemes for Functional Programs. Luis Damas and Robin Milner. POPL 1982.
- Functional Unparsing. Olivier Danvy. BRICS Technical Report RS 98-12, 1998.
- Exhancements to eXene. Dustin B. deBoer. Master of Science Thesis, 2005.

  Describes ways to improve widget concurrency, handling of input focus, X resources and selections.

- A Concurrent, Generational Garbage Collector for a Multithreaded Implementation of ML. Damien Doligez and Xavier Leroy. POPL 1993.
- Modular Type Classes. Derek Dreyer, Robert Harper, Manuel M.T. Chakravarty, Gabriele Keller. University of Chicago Technical Report TR-2007-02, 2006.
- Principal Type Schemes for Modular Programs. Derek Dreyer and Matthias Blume. ESOP 2007.
- Extensional Polymorphism. Catherin Dubois, Francois Rouaix, and Pierre Weis. POPL 1995.

  An extension of ML that allows the definition of ad-hoc polymorphic functions by inspecting the type of their argument.

E

- Garbage Collection Safety for Region-based Memory Management. Martin Elsman. TLDI 2003.
- Type-Specialized Serialization with Sharing. Martin Elsman. University of Copenhagen. IT University Technical Report TR-2004-43, 2004.

F

- The Little MLer (addall). ISBN 026256114X. Matthias Felleisen and Dan Freidman. The MIT Press, 1998.
- Kill-Safe Synchronization Abstractions. Matthew Flatt and Robert Bruce Findler. PLDI 2004.
- Contification Using Dominators. Matthew Fluet and Stephen Weeks. ICFP 2001.

  Describes contification, a generalization of tail-recursion elimination that is an optimization operating on MLton's static single assignment (SSA) intermediate language.

- Phantom Types and Subtyping. Matthew Fluet and Riccardo Pucella. JFP 2006.

- Generic Polymorphism in ML. J. Furuse. JFLA 2001.

  The formalism behind G'CAML, which has an approach to ad-hoc polymorphism based on Dubois95, the differences being in how type checking works an an improved compilation approach for typecase that does the matching at compile time, not run time.

G

- A Multi-Threaded Higher-order User Interface Toolkit. Emden R. Gansner and John H. Reppy. User Interface Software, 1993.
- The Standard ML Basis Library. (addall) ISBN 9780521794787. Emden R. Gansner and John H. Reppy. Cambridge University Press, 2004.

  An introduction and overview of the Basis Library, followed by a detailed description of each module. The module descriptions are also available online.

- Region-based Memory Management in Cyclone. Dan Grossman, Greg Morrisett, Trevor Jim, Michael Hicks, Yanling Wang, and James Cheney. PLDI 2002.

H

- Combining Region Inference and Garbage Collection. Niels Hallenberg, Martin Elsman, and Mads Tofte. PLDI 2002.
- Introduction to Programming Using SML (addall). ISBN 0201398206. Michael R. Hansen, Hans Rischel. Addison-Wesley, 1999.
- Programming in Standard ML. Robert Harper.
- Typing First-Class Continuations in ML. Robert Harper, Bruce F. Duba, and David MacQueen. JFP 1993.
- On the Type Structure of Standard ML. Robert Harper and John C. Mitchell. TOPLAS 1992.
- On the Practicality and Desirability of Highly-concurrent, Mostly-functional Programming. Carl H. Hauser and David B. Benson. ACSD 2004.

  Describes the use of Concurrent ML in implementing the Ped text editor. Argues that using large numbers of threads and message passing style is a practical and effective way of modularizing a program.

- A Functional Description of TeX's Formula Layout. Reinhold Heckmann and Reinhard Wilhelm. JFP 1997.
- Safe and Flexible Memory Management in Cyclone. Mike Hicks, Greg Morrisett, Dan Grossman, and Trevor Jim. University of Maryland Technical Report CS-TR-4514, 2003.
- Compiling HOL4 to Native Code. Joe Hurd. TPHOLs 2004.

  Describes a port of HOL from Moscow ML to MLton, the difficulties encountered in compiling large programs, and the speedups achieved (roughly 10x).

I

J

- Garbage Collection: Algorithms for Automatic Memory Management (addall). ISBN 0471941484. Richard Jones. John Wiley & Sons, 1999.

K

- Mistakes and Ambiguities in the Definition of Standard ML. Stefan Kahrs. University of Edinburgh Technical Report ECS-LFCS-93-257, 1993.

  Describes a number of problems with the 1990 Definition, many of which were fixed in the 1997 Definition.
  Also see the addenda published in 1996.

- Generics for the Working ML'er. Vesa Karvonen. ML 2007. Slides from the presentation are also available.
- Pickler Combinators. Andrew Kennedy. JFP 2004.
- sml2java: A Source To Source Translator. Justin Koser, Haakon Larsen, Jeffrey A. Vaughan. DPCOOL 2003.

L

- Faster Algorithms for Finding Minimal Consistent DFAs. Kevin Lang. 1999.
- mGTK: An SML binding of Gtk+. Ken Larsen and Henning Niss. USENIX Annual Technical Conference, 2004.
- An LLVM Back-end for MLton. Brian Leibig. MS Project Report, 2013.

  Describes MLton's LLVMCodegen.

- The ZINC Experiment: an Economical Implementation of the ML Language. Xavier Leroy. Technical report 117, INRIA, 1990.

  A detailed explanation of the design and implementation of a bytecode compiler and interpreter for ML with a machine model aimed at efficient implementation.

- Polymorphism by Name for References and Continuations. Xavier Leroy. POPL 1993.
- MLRISC Annotations. Allen Leung and Lal George. 1999.

M

- Asynchronous Exceptions in Haskell. Simon Marlow, Simon Peyton Jones, Andy Moran and John Reppy. PLDI 2001.

  An asynchronous exception is a signal that one thread can send to another, and is useful for the receiving thread to treat as an exception so that it can clean up locks or other state relevant to its current context.

- An Ideal Model for Recursive Polymorphic Types. David MacQueen, Gordon Plotkin, Ravi Sethi. POPL 1984.
- A Distributed Concurrent Implementation of Standard ML. David Matthews. University of Edinburgh Technical Report ECS-LFCS-91-174, 1991.
- Papers on Poly/ML. David C. J. Matthews. University of Edinburgh Technical Report ECS-LFCS-95-335, 1995.
- That About Wraps it Up: Using FIX to Handle Errors Without Exceptions, and Other Programming Tricks. Bruce J. McAdam. University of Edinburgh Technical Report ECS-LFCS-97-375, 1997.
- A Just-In-Time Backend for Moscow ML 2.00 in SML. Bjarke Meier, Kristian Nørgaard. Masters Thesis, 2003.

  A just-in-time compiler using GNU Lightning, showing a speedup of up to four times over Moscow ML's usual bytecode interpreter.
  The full report is only available in Danish.

- A Theory of Type Polymorphism in Programming. Robin Milner. Journal of Computer and System Sciences, 1978.
- How ML Evolved. Robin Milner. Polymorphism—The ML/LCF/Hope Newsletter, 1983.

* Commentary on Standard ML (addall) ISBN 0262631377. Robin Milner and Mads Tofte. The MIT Press, 1991.

  Introduces and explains the notation and approach used in The Definition of Standard ML.

* The Definition of Standard ML. (addall) ISBN 0262631326. Robin Milner, Mads Tofte, and Robert Harper. The MIT Press, 1990.

  Superseded by The Definition of Standard ML (Revised). Accompanied by the Commentary on Standard ML.

* The Definition of Standard ML (Revised). (addall) ISBN 0262631814. Robin Milner, Mads Tofte, Robert Harper, and David MacQueen. The MIT Press, 1997.

  A terse and formal specification of Standard ML's syntax and semantics. Supersedes The Definition of Standard ML.

* Principles and a Preliminary Design for ML2000. The ML2000 working group, 1999.
* Automatic Code Generation from Coloured Petri Nets for an Access Control System. Kjeld H. Mortensen. Workshop on Practical Use of Coloured Petri Nets and Design/CPN, 1999.
* Procs and Locks: a Portable Multiprocessing Platform for Standard ML of New Jersey. J. Gregory Morrisett and Andrew Tolmach. PPoPP 1993.
* ML Grid Programming with ConCert. Tom Murphy VII. ML 2006.

N

* fxp - Processing Structured Documents in SML. Andreas Neumann. Scottish Functional Programming Workshop, 1999.

  Describes fxp, an XML parser implemented in Standard ML.

* Parsing and Querying XML Documents in SML. Andreas Neumann. Doctoral Thesis, 1999.
* Compiling ML Polymorphism with Explicit Layout Bitmap. Huu-Duc Nguyen and Atsushi Ohori. PPDP 2006.

O

* Purely Functional Data Structures. ISBN 9780521663502. Chris Okasaki. Cambridge University Press, 1999.
* A Simple Semantics for ML Polymorphism. Atsushi Ohori. FPCA 1989.
* A Polymorphic Record Calculus and Its Compilation. Atsushi Ohori. TOPLAS 1995.
* An Unboxed Operational Semantics for ML Polymorphism. Atsushi Ohori and Tomonobu Takamizawa. LASC 1997.
* Type-Directed Specialization of Polymorphism. Atsushi Ohori. IC 1999.
* Regular-expression derivatives reexamined. Scott Owens, John Reppy, and Aaron Turon. JFP 2009.

P

* ML For the Working Programmer (addall) ISBN 052156543X. Larry C. Paulson. Cambridge University Press, 1996.
* The HiPE/x86 Erlang Compiler: System Description and Performance Evaluation. Mikael Pettersson, Konstantinos Sagonas, and Erik Johansson. FLOPS 2002.

  Describes a native x86 Erlang compiler and a comparison of many different native x86 compilers (including MLton) and their register usage and call stack implementations.

* User's Guide to ML-Lex and ML-Yacc Roger Price. 2009.
* Reactive Programming in Standard ML. Riccardo R. Puccella. 1998. ICCL 1998.

Q

R

- Concurrent Programming in ML. Norman Ramsey. Princeton University Technical Report CS-TR-262-90, 1990.
- Embedding an Interpreted Language Using Higher-Order Functions and Types. Norman Ramsey. JFP 2011.
- An Expressive Language of Signatures. Norman Ramsey, Kathleen Fisher, and Paul Govereau. ICFP 2005.
- Widening Integer Arithmetic. Kevin Redwine and Norman Ramsey. CC 2004.

  Describes a method to implement numeric types and operations (like `Int31` or `Word17`) for sizes smaller than that provided by the processor.

- Synchronous Operations as First-Class Values. John Reppy. PLDI 1988.
- Concurrent Programming in ML (addall). ISBN 9780521714723. John Reppy. Cambridge University Press, 2007.

  Describes ConcurrentML.

- Definitional Interpreters Revisited. John C. Reynolds. HOSC 1998.
- Definitional Interpreters for Higher-Order Programming Languages John C. Reynolds. HOSC 1998.
- Defects in the Revised Definition of Standard ML. Andreas Rossberg. 2001.

S

- Dual-Mode Garbage Collection. Patrick M. Sansom. Workshop on the Parallel Implementation of Functional Languages, 1991.
- When Do Match-Compilation Heuristics Matter. Kevin Scott and Norman Ramsey. University of Virginia Technical Report CS-2000-13, 2000.

  Modified SML/NJ to experimentally compare a number of match-compilation heuristics and showed that choice of heuristic usually does not significantly affect code size or run time.

- ML Pattern Match Compilation and Partial Evaluation. Peter Sestoft. Partial Evaluation, 1996.

  Describes the derivation of the match compiler used in Moscow ML.

- Space-Efficient Closure Representations. Zhong Shao and Andrew W. Appel. LFP 1994.
- Unix System Programming with Standard ML. Anthony L. Shipman. 2002.

  Includes a description of the Swerve HTTP server written in SML.

- Calcul Statique des Applications de Modules Parametres. Julien Signoles. JFLA 2003.

  Describes a defunctorizer for OCaml, and compares it to existing defunctorizers, including MLton.

- Incremental Execution of Transformation Specifications. Ganesh Sittampalam, Oege de Moor, and Ken Friis Larsen. POPL 2004.

  Mentions a port from Moscow ML to MLton of MuDDY, an SML wrapper around the BuDDY BDD package.

- A Separate Compilation Extension to Standard ML. David Swasey, Tom Murphy VII, Karl Crary and Robert Harper. ML 2006.

T

- ML-Yacc User's Manual. Version 2.4 David R. Tarditi and Andrew W. Appel. 2000.
- No Assembly Required: Compiling Standard ML to C. David Tarditi, Peter Lee, and Anurag Acharya. 1990.
- Object-oriented programming and Standard ML. Lars Thorup and Mads Tofte. ML, 1994.
- Type Inference for Polymorphic References. Mads Tofte. IC 1990.
- Essentials of Standard ML Modules. Mads Tofte.
- Tips for Computer Scientists on Standard ML (Revised). Mads Tofte.
- A Debugger for Standard ML. Andrew Tolmach and Andrew W. Appel. JFP 1995.
- Combining Closure Conversion with Closure Analysis using Algebraic Types. Andrew Tolmach. TIC 1997.

  Describes a closure-conversion algorithm for a monomorphic IL. The algorithm uses a unification-based flow analysis followed by defunctionalization and is similar to the approach used in MLton (CejtinEtAl00).

- From ML to Ada: Strongly-typed Language Interoperability via Source Translation. Andrew Tolmach and Dino Oliva. JFP 1998.

  Describes a compiler for RML, a core SML-like language. The compiler is similar in structure to MLton, using monomorphisation, defunctionalization, and optimization on a first-order IL.

U

- Elements of ML Programming (addall). ISBN 0137903871. Jeffrey D. Ullman. Prentice-Hall, 1998.

V

W

- A Types-as-Sets Semantics for Milner-Style Polymorphism. Mitchell Wand. POPL 1984.
- Managing Memory with Types. Daniel C. Wang. PhD Thesis.

  Chapter 6 describes an implementation of a type-preserving garbage collector for MLton.

- Type-Preserving Garbage Collectors. Daniel C. Wang and Andrew W. Appel. POPL 2001.

  Shows how to modify MLton to generate a strongly-typed garbage collector as part of a program.

- Programming With Recursion Schemes. Daniel C. Wang and Tom Murphy VII.

  Describes a programming technique for data abstraction, along with benchmarks of MLton and other SML compilers.

- Whole-Program Compilation in MLton. Stephen Weeks. ML 2006.
- Simple Imperative Polymorphism. Andrew Wright. LASC, 8(4):343-355, 1995.

  The origin of the ValueRestriction.

X

Y

- Encoding Types in ML-like Languages. Zhe Yang. ICFP 1998.

Z

- Stabilizers: A Modular Checkpointing Abstraction for Concurrent Functional Programs. Lukasz Ziarek, Philip Schatz, and Suresh Jagannathan. ICFP 2006.
- Flattening tuples in an SSA intermediate representation. Lukasz Ziarek, Stephen Weeks, and Suresh Jagannathan. HOSC 2008.

Abbreviations

- ACSD = International Conference on Application of Concurrency to System Design
- BABEL = Workshop on multi-language infrastructure and interoperability
- CC = International Conference on Compiler Construction
- DPCOOL = Workshop on Declarative Programming in the Context of OO Languages
- ESOP = European Symposium on Programming
- FLOPS = Symposium on Functional and Logic Programming
- FPCA = Conference on Functional Programming Languages and Computer Architecture
- HOSC = Higher-Order and Symbolic Computation
- IC = Information and Computation
- ICCL = IEEE International Conference on Computer Languages
- ICFP = International Conference on Functional Programming
- IFL = International Workshop on Implementation and Application of Functional Languages
- IVME = Workshop on Interpreters, Virtual Machines and Emulators
- JFLA = Journees Francophones des Langages Applicatifs
- JFP = Journal of Functional Programming
- LASC = Lisp and Symbolic Computation
- LFP = Lisp and Functional Programming
- ML = Workshop on ML
- PLDI = Conference on Programming Language Design and Implementation
- POPL = Symposium on Principles of Programming Languages
- PPDP = International Conference on Principles and Practice of Declarative Programming
- PPoPP = Principles and Practice of Parallel Programming
- TCS = IFIP International Conference on Theoretical Computer Science
- TIC = Types in Compilation
- TLDI = Workshop on Types in Language Design and Implementation
- TOPLAS = Transactions on Programming Languages and Systems
- TPHOLs = International Conference on Theorem Proving in Higher Order Logics

RefFlatten

RefFlatten is an optimization pass for the SSA2 IntermediateLanguage, invoked from SSA2Simplify.

Description

This pass flattens a `ref` cell into its containing object. The idea is to replace, where possible, a type like

```
(int ref * real)
```

with a type like

```
(int[m] * real)
```

where the `[m]` indicates a mutable field of a tuple.

Implementation

- `ref-flatten.fun`

Details and Notes

The savings is obvious, I hope. We avoid an extra heap-allocated object for the `ref`, which in the above case saves two words. We also save the time and code for the extra indirection at each get and set. There are lots of useful data structures (singly-linked and doubly-linked lists, union-find, Fibonacci heaps, . . .) that I believe we are paying through the nose right now because of the absence of ref flattening.

The idea is to compute for each occurrence of a `ref` type in the program whether or not that `ref` can be represented as an offset of some object (constructor or tuple). As before, a unification-based whole-program with deep abstract values makes sure the analysis is consistent.

The only syntactic part of the analysis that remains is the part that checks that for a variable bound to a value constructed by `Ref_ref`:

- the object allocation is in the same block. This is pretty draconian, and it would be nice to generalize it some day to allow flattening as long as the `ref` allocation and object allocation "line up one-to-one" in the same loop-free chunk of code.
- updates occur in the same block (and hence it is safe-for-space because the containing object is still alive). It would be nice to relax this to allow updates as long as it can be provedthat the container is live.

Prevent flattening of `unit ref`-s.

RefFlatten is safe for space. The idea is to prevent a `ref` being flattened into an object that has a component of unbounded size (other than possibly the `ref` itself) unless we can prove that at each point the `ref` is live, then the containing object is live too. I used a pretty simple approximation to liveness.

Regions

In region-based memory management, the heap is divided into a collection of regions into which objects are allocated. At compile time, either in the source program or through automatic inference, allocation points are annotated with the region in which the allocation will occur. Typically, although not always, the regions are allocated and deallocated according to a stack discipline.

MLton does not use region-based memory management; it uses traditional GarbageCollection. We have considered integrating regions with MLton, but in our opinion it is far from clear that regions would provide MLton with improved performance, while they would certainly add a lot of complexity to the compiler and complicate reasoning about and achieving SpaceSafety. Region-based memory management and garbage collection have different strengths and weaknesses; it's pretty easy to come up with programs that do significantly better under regions than under GC, and vice versa. We believe that it is the case that common SML idioms tend to work better under GC than under regions.

One common argument for regions is that the region operations can all be done in (approximately) constant time; therefore, you eliminate GC pause times, leading to a real-time GC. However, because of space safety concerns (see below), we believe that region-based memory management for SML must also include a traditional garbage collector. Hence, to achieve real-time memory management for MLton/SML, we believe that it would be both easier and more efficient to implement a traditional real-time garbage collector than it would be to implement a region system.

Regions, the ML Kit, and space safety

The ML Kit pioneered the use of regions for compiling Standard ML. The ML Kit maintains a stack of regions at run time. At compile time, it uses region inference to decide when data can be allocated in a stack-like manner, assigning it to an appropriate region. The ML Kit has put a lot of effort into improving the supporting analyses and representations of regions, which are all necessary to improve the performance.

Unfortunately, under a pure stack-based region system, space leaks are inevitable in theory, and costly in practice. Data for which region inference can not determine the lifetime is moved into the "global region" whose lifetime is the entire program. There are two ways in which region inference will place an object to the global region.

- When the inference is too conservative, that is, when the data is used in a stack-like manner but the region inference can't figure it out.
- When data is not used in a stack-like manner. In this case, correctness requires region inference to place the object

This global region is a source of space leaks. No matter what region system you use, there are some programs such that the global region must exist, and its size will grow to an unbounded multiple of the live data size. For these programs one must have a GC to achieve space safety.

To solve this problem, the ML Kit has undergone work to combine garbage collection with region-based memory management. HallenbergEtAl02 and Elsman03 describe the addition of a garbage collector to the ML Kit's region-based system. These papers provide convincing evidence for space leaks in the global region. They show a number of benchmarks where the memory usage of the program running with just regions is a large multiple (2, 10, 50, even 150) of the program running with regions plus GC.

These papers also give some numbers to show the ML Kit with just regions does better than either a system with just GC or a combined system. Unfortunately, a pure region system isn't practical because of the lack of space safety. And the other performance numbers are not so convincing, because they compare to an old version of SML/NJ and not at all with MLton. It would be interesting to see a comparison with a more serious collector.

Regions, Garbage Collection, and Cyclone

One possibility is to take Cyclone's approach, and provide both region-based memory management and garbage collection, but at the programmer's option (GrossmanEtAl02, HicksEtAl03).

One might ask whether we might do the same thing — i.e., provide a `MLton.Regions` structure with explicit region based memory management operations, so that the programmer could use them when appropriate. MatthewFluet has thought about this question

- http://www.cs.cornell.edu/People/fluet/rgn-monad/index.html

Unfortunately, his conclusion is that the SML type system is too weak to support this option, although there might be a "poor-man's" version with dynamic checks.

Release20041109

This is an archived public release of MLton, version 20041109.

Changes since the last public release

- New platforms:
  - x86: FreeBSD 5.x, OpenBSD
  - PowerPC: Darwin (MacOSX)
- Support for the ML Basis system, a new mechanism supporting programming in the very large, separate delivery of library sources, and more.
- Support for dynamic libraries.
- Support for ConcurrentML (CML).
- New structures: `Int2`, `Int3`, ..., `Int31` and `Word2`, `Word3`, ..., `Word31`.
- Front-end bug fixes and improvements.
- A new form of profiling with `-profile count`, which can be used to test code coverage.
- A bytecode generator, available via `-codegen bytecode`.
- Representation improvements:
  - Tuples and datatypes are packed to decrease space usage.
  - Ref cells may be unboxed into their containing object.
  - Arrays of tuples may represent the tuples unboxed.

For a complete list of changes and bug fixes since 20040227, see the `changelog`.

Also see

- Bugs20041109

Release20051202

This is an archived public release of MLton, version 20051202.

Changes since the last public release

- The MLton license is now BSD-style instead of the GPL.
- New platforms: X86/MinGW and HPPA/Linux.
- Improved and expanded documentation, based on the MLton wiki.
- Compiler.
  - improved exception history.
  - Command-line switches.
    * Added: -as-opt, -mlb-path-map, -target-as-opt, -target-cc-opt.
    * Removed: -native, -sequence-unit, -warn-match, -warn-unused.
- Language.
  - FFI syntax changes and extensions.
    * Added: _symbol.
    * Changed: _export, _import.
    * Removed: _ffi.
  - ML Basis annotations.
    * Added: allowFFI, nonexhaustiveExnMatch, nonexhaustiveMatch, redundantMatch, sequenceNonUnit.
    * Deprecated: allowExport, allowImport, sequenceUnit, warnMatch.
- Libraries.
  - Basis Library.
    * Added: Int1, Word1.
  - MLton structure.
    * Added: Process.create, ProcEnv.setgroups, Rusage.measureGC, Socket.fdToSock, Socket.Ctl.getError.
    * Changed: MLton.Platform.Arch.
  - Other libraries.
    * Added: ckit, ML-NLFFI library, SML/NJ library.
- Tools.
  - Updates of mllex and mlyacc from SML/NJ.
  - Added mlnlffigen.
  - Profiling supports better inclusion/exclusion of code.

For a complete list of changes and bug fixes since Release20041109, see the changelog and Bugs20041109.

20051202 binary packages

- x86
  - Cygwin 1.5.18-1
  - FreeBSD 5.4
  - Linux
    * Debian sid
    * Debian stable (Sarge)
    * RedHat 7.1-9.3 FC1-FC4
    * tgz for other distributions (glibc 2.3)
  - MinGW
  - NetBSD 2.0.2
  - OpenBSD 3.7
- PowerPC
  - Darwin 7.9.0 (Mac OS X)
- Sparc
  - Solaris 8

20051202 source packages

- source tgz
- Debian dsc, diff.gz, orig.tar.gz
- RedHat source rpm

Packages available at other sites

- Debian
- FreeBSD
- Fedora Core 4 5
- Ubuntu

Also see

- Bugs20051202
- MLton Guide (20051202).
  A snapshot of the MLton wiki at the time of release.

Release20070826

This is an archived public release of MLton, version 20070826.

Changes since the last public release

- New platforms:
  - AMD64/Linux, AMD64/FreeBSD
  - HPPA/HPUX
  - PowerPC/AIX
  - X86/Darwin (Mac OS X)
- Compiler.
  - Support for 64-bit platforms.
    - Native amd64 codegen.
  - Compile-time options.
    - Added: `-codegen amd64`, `-codegen x86`, `-default-type` *`type`*, `-profile-val {false|true}`.
    - Changed: `-stop f` (file listing now includes `.mlb` files).
  - Bytecode codegen.
    - Support for exception history.
    - Support for profiling.
- Language.
  - ML Basis annotations.
    - Removed: `allowExport`, `allowImport`, `sequenceUnit`, `warnMatch`.
- Libraries.
  - Basis Library.
    - Added: `PackWord16Big`, `PackWord16Little`, `PackWord64Big`, `PackWord64Little`.
    - Bug fixes: see `changelog`.
  - MLton structure.
    - Added: `MLTON_MONO_ARRAY`, `MLTON_MONO_VECTOR`, `MLTON_REAL`, `MLton.BinIO.tempPrefix`, `MLton.CharArray`, `MLton.CharVector`, `MLton.Exn.defaultTopLevelHandler`, `MLton.Exn.getTopLevelHandler`, `MLton.Exn.setTopLevelHandler`, `MLton.IntInf.BigWord`, `Mlton.IntInf.SmallInt`, `MLton.LargeReal`, `MLton.LargeWord`, `MLton.Real`, `MLton.Real32`, `MLton.Real64`, `MLton.Rlimit.Rlim`, `MLton.TextIO.tempPrefix`, `MLton.Vector.create`, `MLton.Word.bswap`, `MLton.Word8.bswap`, `MLton.Word16`, `MLton.Word32`, `MLton.Word64`, `MLton.Word8Array`, `MLton.Word8Vector`.
    - Changed: `MLton.Array.unfoldi`, `MLton.IntInf.rep`, `MLton.Rlimit`, `MLton.Vector.unfoldi`.
    - Deprecated: `MLton.Socket`.
  - Other libraries.
    - Added: MLRISC library.
    - Updated: ckit library, SML/NJ library.
- Tools.

For a complete list of changes and bug fixes since Release20051202, see the `changelog` and Bugs20051202.

20070826 binary packages

- AMD64
  - Linux, glibc 2.3
- HPPA
  - HPUX 11.00 and above, statically linked against GnuMP
- PowerPC
  - AIX 5.1 and above, statically linked against GnuMP
  - Darwin 8.10 (Mac OS X), statically linked against GnuMP
  - Darwin 8.10 (Mac OS X), dynamically linked against GnuMP in `/opt/local/lib` (suitable for MacPorts install of GnuMP)
- Sparc
  - Solaris 8 and above, statically linked against GnuMP
- X86
  - Cygwin 1.5.24-2
  - Darwin (.tgz) 8.10 (Mac OS X), dynamically linked against GnuMP in `/opt/local/lib` (suitable for MacPorts install of GnuMP)
  - Darwin (.dmg) 8.10 (Mac OS X), dynamically linked against GnuMP in `/opt/local/lib` (suitable for MacPorts install of GnuMP)
  - Darwin (.tgz) 8.10 (Mac OS X), statically linked against GnuMP
  - Darwin (.dmg) 8.10 (Mac OS X), statically linked against GnuMP
  - FreeBSD
  - Linux, glibc 2.3
  - Linux, glibc 2.1, statically linked against GnuMP
  - MinGW, dynamically linked against GnuMP (requires `libgmp-3.dll`)
  - MinGW, statically linked against GnuMP

20070826 source packages

- source tgz
- Debian dsc, diff.gz, orig.tar.gz

Packages available at other sites

- Debian
- FreeBSD
- Fedora
- Ubuntu

Also see

- Bugs20070826
- MLton Guide (20070826).
  A snapshot of the MLton wiki at the time of release.

Release20100608

This is an archived public release of MLton, version 20100608.

Changes since the last public release

- New platforms.
  - AMD64/Darwin (Mac OS X Snow Leopard)
  - IA64/HPUX
  - PowerPC64/AIX
- Compiler.
  - Command-line switches.
    - Added: `-mlb-path-var <name> <value>`
    - Removed: `-keep sml`, `-stop sml`
  - Improved constant folding of floating-point operations.
  - Experimental: Support for compiling to a C library; see documentation.
  - Extended `-show-def-use output` to include types of variable definitions.
  - Deprecated features (to be removed in a future release)
    - Bytecode codegen: The bytecode codegen has not seen significant use and it is not well understood by any of the active developers.
    - Support for `.cm` files as input: The ML Basis system provides much better infrastructure for "programming in the very large" than the (very) limited support for CM. The `cm2mlb` tool (available in the source distribution) can be used to convert CM projects to MLB projects, preserving the CM scoping of module identifiers.
  - Bug fixes: see `changelog`
- Runtime.
  - @MLton switches.
    - Added: `may-page-heap {false|true}`
  - `may-page-heap`: By default, MLton will not page the heap to disk when unable to grow the heap to accommodate an allocation. (Previously, this behavior was the default, with no means to disable, with security an least-surprise issues.)
  - Bug fixes: see `changelog`
- Language.
  - Allow numeric characters in ML Basis path variables.
- Libraries.
  - Basis Library.
    - Bug fixes: see `changelog`
  - MLton structure.
    - Added: `MLton.equal`, `MLton.hash`, `MLton.Cont.isolate`, `MLton.GC.Statistics`, `MLton.Pointer.sizeofPointer`, `MLton.Socket.Address.toVector`
    - Changed:
    - Deprecated: `MLton.Socket`
  - Unsafe structure.

    * Added versions of all of the monomorphic array and vector structures.

  – Other libraries.

    * Updated: ckit library, MLRISC library, SML/NJ library.

- Tools.

  – `mllex`

    * Eliminated top-level `type int =Int.int` in output.
    * Include `(*#line line:col "file.lex" *)` directives in output.
    * Added `%posint` command, to set the `yypos` type and allow the lexing of multi-gigabyte files.

  – `mlnlffigen`

    * Added command-line switches `-linkage archive` and `-linkage shared`.
    * Deprecated command-line switch `-linkage static`.
    * Added support for IA64 and HPPA targets.

  – `mlyacc`

    * Eliminated top-level `type int =Int.int` in output.
    * Include `(*#line line:col "file.grm" *)` directives in output.

For a complete list of changes and bug fixes since Release20070826, see the `changelog` and Bugs20070826.

20100608 binary packages

- AMD64 (aka "x86-64" or "x64")

  – Darwin (.tgz) 10.3 (Mac OS X Snow Leopard), dynamically linked against GnuMP in `/opt/local/lib` (suitable for MacPorts install of GnuMP)
  – Darwin (.tgz) 10.3 (Mac OS X Snow Leopard), statically linked against GnuMP (but requires GnuMP for generated executables)
  – Linux, glibc 2.11
  – Linux, statically linked
  – Windows MinGW 32/64 self-extracting (28MB) or MSI (61MB) installer

- X86

  – Cygwin 1.7.5
  – Darwin (.tgz) 9.8 (Mac OS X Leopard), dynamically linked against GnuMP in `/opt/local/lib` (suitable for MacPorts install of GnuMP)
  – Darwin (.tgz) 9.8 (Mac OS X Leopard), statically linked against GnuMP (but requires GnuMP for generated executables)
  – Linux, glibc 2.11
  – Linux, statically linked
  – Windows MinGW 32/64 self-extracting (28MB) or MSI (61MB) installer

20100608 source packages

- mlton-20100608.src.tgz

Packages available at other sites

- Debian
- FreeBSD
- Fedora
- Ubuntu

Also see

- Bugs20100608
- MLton Guide (20100608).
  A snapshot of the MLton wiki at the time of release.

Release20130715

This is an archived public release of MLton, version 20130715.

Changes since the last public release

- Compiler.
  - Cosmetic improvements to type-error messages.
  - Removed features:
    * Bytecode codegen: The bytecode codegen had not seen significant use and it was not well understood by any of the active developers.
    * Support for `.cm` files as input: The ML Basis system provides much better infrastructure for "programming in the very large" than the (very) limited support for CM. The `cm2mlb` tool (available in the source distribution) can be used to convert CM projects to MLB projects, preserving the CM scoping of module identifiers.
  - Bug fixes: see `changelog`
- Runtime.
  - Bug fixes: see `changelog`
- Language.
  - Interpret `(*#line line:col "file" *)` directives as relative file names.
  - ML Basis annotations.
    * Added: `resolveScope`
- Libraries.
  - Basis Library.
    * Improved performance of `String.concatWith`.
    * Use bit operations for `REAL.class` and other low-level operations.
    * Support additional variables with `Posix.ProcEnv.sysconf`.
    * Bug fixes: see `changelog`
  - MLton structure.
    * Removed: `MLton.Socket`
  - Other libraries.
    * Updated: ckit library, MLRISC library, SML/NJ library
    * Added: MLLPT library
- Tools.
  - `mllex`
    * Generate `(*#line line:col "file.lex" *)` directives with simple (relative) file names, rather than absolute paths.
  - `mlyacc`
    * Generate `(*#line line:col "file.grm" *)` directives with simple (relative) file names, rather than absolute paths.
    * Fixed bug in comment-handling in lexer.

For a complete list of changes and bug fixes since Release20100608, see the `changelog` and Bugs20100608.

20130715 binary packages

- AMD64 (aka "x86-64" or "x64")
  - Darwin (.tgz) 11.4 (Mac OS X Lion), dynamically linked against GnuMP in `/opt/local/lib` (suitable for MacPorts install of GnuMP)
  - Darwin (.tgz) 11.4 (Mac OS X Lion), statically linked against GnuMP (but requires GnuMP for generated executables)
  - Linux, glibc 2.15
- X86
  - Linux, glibc 2.15

20130715 source packages

- mlton-20130715.src.tgz

Downstream packages

- Debian
- FreeBSD
- Fedora
- Ubuntu

Also see

- Bugs20130715
- MLton Guide (20130715).
  A snapshot of the MLton website at the time of release.

Release20180207

Here you can download the latest public release of MLton, version 20180207.

Changes since the last public release

- Compiler.
  - Added an experimental LLVM codegen (`-codegen llvm`); requires LLVM tools (`llvm-as`, `opt`, `llc`) version $\geq$ 3.7.
  - Made many substantial cosmetic improvements to front-end diagnostic messages, especially with respect to source location regions, type inference for `fun` and `val rec` declarations, signature constraints applied to a structure, `sharing type` specifications and `where type` signature expressions, type constructor or type variable escaping scope, and nonexhaustive pattern matching.
  - Fixed minor bugs with exception replication, precedence parsing of function clauses, and simultaneous `sharing` of multiple structures.
  - Made compilation deterministic (eliminate output executable name from compile-time specified `@MLton` runtime arguments; deterministically generate magic constant for executable).
  - Updated `-show-basis` (recursively expand structures in environments, displaying components with long identifiers; append `(* @region *)` annotations to items shown in environment).
  - Forced amd64 codegen to generate PIC on amd64-linux targets.
- Runtime.
  - Added `gc-summary-file file` runtime option.
  - Reorganized runtime support for `IntInf` operations so that programs that do not use `IntInf` compile to executables with no residual dependency on GMP.
  - Changed heap representation to store forwarding pointer for an object in the object header (rather than in the object data and setting the header to a sentinel value).
- Language.
  - Added support for selected SuccessorML features; see http://mlton.org/SuccessorML for details.
  - Added `(*#showBasis "file" *)` directive; see http://mlton.org/ShowBasisDirective for details.
  - FFI:
    - Added `pure`, `impure`, and `reentrant` attributes to `_import`. An unattributed `_import` is treated as `impure`. A `pure _import` may be subject to more aggressive optimizations (common subexpression elimination, dead-code elimination). An `_import`-ed C function that (directly or indirectly) calls an `_export`-ed SML function should be attributed `reentrant`.
  - ML Basis annotations.
    - Added `allowSuccessorML {false|true}` to enable all SuccessorML features and other annotations to enable specific SuccessorML features; see http://mlton.org/SuccessorML for details.
    - Split `nonexhaustiveMatch {warn|error|igore}` and `redundantMatch {warn|error|ignore}` into `nonexhaustiveMatch` and `redundantMatch` (controls diagnostics for `case` expressions, `fn` expressions, and `fun` declarations (which may raise `Match` on failure)) and `nonexhaustiveBind` and `redundantBind` (controls diagnostics for `val` declarations (which may raise `Bind` on failure)).
    - Added `valrecConstr {warn|error|ignore}` to report when a `val rec` (or `fun`) declaration redefines an identifier that previously had constructor status.
- Libraries.
  - Basis Library.

    * Improved performance of `Array.copy`, `Array.copyVec`, `Vector.append`, `String.^`, `String.concat`, `String.concatWith`, and other related functions by using `memmove` rather than element-by-element constructions.
  - `Unsafe` structure.
    * Added unsafe operations for array uninitialization and raw arrays; see https://github.com/MLton/mlton/pull/207 for details.
  - Other libraries.
    * Updated: ckit library, MLLPT library, MLRISC library, SML/NJ library

- Tools.
  - mlnlffigen
    * Updated to warn and skip (rather than abort) when encountering functions with `struct`/`union` argument or return type.

For a complete list of changes and bug fixes since Release20130715, see the `CHANGELOG.adoc` and Bugs20130715.

20180207 binary packages

- AMD64 (aka "x86-64" or "x64")
  - Darwin (.tgz) 16.7 (Mac OS X Sierra), dynamically linked against GnuMP in `/usr/local/lib` (suitable for Homebrew install of GnuMP)
  - Darwin (.tgz) 16.7 (Mac OS X Sierra), statically linked against GnuMP (but requires GnuMP for generated executables)
  - Linux, glibc 2.23

20180207 source packages

- mlton-20180207.src.tgz

Also see

- Bugs20180207
- MLton Guide (20180207).

  A snapshot of the MLton website at the time of release.

ReleaseChecklist

Advance preparation for release

- Update `./CHANGELOG.adoc`.
  - Write entries for missing notable commits.
  - Write summary of changes from previous release.
  - Update with estimated release date.
- Update `./README.adoc`.
  - Check features and description.
- Update `man/{mlton,mlprof}.1`.
  - Check compile-time and run-time options in `man/mlton.1`.
  - Check options in `man/mlprof.1`.
  - Update with estimated release date.
- Update `doc/guide`.
  - Synchronize Features page with `./README.adoc`.
  - Update Credits page with acknowledgements.
  - Create **ReleaseYYYYMM??** page (i.e., forthcoming release) based on **ReleaseXXXXLLCC** (i.e., previous release).
    * Update summary from `./CHANGELOG.adoc`.
    * Update links to estimated release date.
  - Create **BugsYYYYMM??** page based on **BugsXXXXLLCC**.
    * Update links to estimated release date.
  - Spell check pages.
- Ensure that all updates are pushed to `master` branch of `mlton`.

Prepare sources for tagging

- Update `./CHANGELOG.adoc`.
  - Update with proper release date.
- Update `man/{mlton,mlprof}.1`.
  - Update with proper release date.
- Update `doc/guide`.
  - Rename **ReleaseYYYYMM??** to **ReleaseYYYYMMDD** with proper release date.
    * Update links with proper release date.
  - Rename **BugsYYYYMM??** to **BugsYYYYMMDD** with proper release date.
    * Update links with proper release date.
  - Update **ReleaseXXXXLLCC**.
    * Change intro to "`This is an archived public release of MLton, version XXXXLLCC.`"
  - Update Home with note of new release.
    * Change `What's new?` text to `Please try out our new release, <:ReleaseYYYYMMDD:MLton YYYYMMDD>.`
    * Update `Download` link with proper release date.
  - Update Releases with new release.
- Ensure that all updates are pushed to `master` branch of `mlton`.

Tag sources

- Shell commands:

```
git clone http://github.com/MLton/mlton mlton.git
cd mlton.git
git checkout master
git tag -a -m "Tagging YYYYMMDD release" on-YYYYMMDD-release master
git push origin on-YYYYMMDD-release
```

Packaging

SourceForge FRS

- Create **YYYYMMDD** directory:

```
sftp user@frs.sourceforge.net:/home/frs/project/mlton/mlton
sftp> mkdir YYYYMMDD
sftp> quit
```

Source release

- Create `mlton-YYYYMMDD.src.tgz`:

```
git clone http://github.com/MLton/mlton mlton
cd mlton
git checkout on-YYYYMMDD-release
make MLTON_VERSION=YYYYMMDD source-release
cd ..
```

  or

```
wget https://github.com/MLton/mlton/archive/on-YYYYMMDD-release.tar.gz
tar xzvf on-YYYYMMDD-release.tar.gz
cd mlton-on-YYYYMMDD-release
make MLTON_VERSION=YYYYMMDD source-release
cd ..
```

- Upload `mlton-YYYYMMDD.src.tgz`:

```
scp mlton-YYYYMMDD.src.tgz user@frs.sourceforge.net:/home/frs/project/mlton/mlton/YYYYMMDD ↩
    /
```

- Update **ReleaseYYYYMMDD** with `mlton-YYYYMMDD.src.tgz` link.

Binary releases

- Build and create `mlton-YYYYMMDD-1.ARCH-OS.tgz`:

```
wget http://sourceforge.net/projects/mlton/files/mlton/YYYYMMDD/mlton-YYYYMMDD.src.tgz
tar xzvf mlton-YYYYMMDD.src.tgz
cd mlton-YYYYMMDD
make binary-release
cd ..
```

- Upload `mlton-YYYYMMDD-1.ARCH-OS.tgz`:

```
scp mlton-YYYYMMDD-1.ARCH-OS.tgz user@frs.sourceforge.net:/home/frs/project/mlton/mlton/ ↩
    YYYYMMDD/
```

- Update **ReleaseYYYYMMDD** with `mlton-YYYYMMDD-1.ARCH-OS.tgz` link.

Website

- guide/YYYYMMDD gets a copy of doc/guide/localhost.
- Shell commands:

```
wget http://sourceforge.net/projects/mlton/files/mlton/YYYYMMDD/mlton-YYYYMMDD.src.tgz
tar xzvf mlton-YYYYMMDD.src.tgz
cd mlton-YYYYMMDD
cd doc/guide
cp -prf localhost YYYYMMDD
tar czvf guide-YYYYMMDD.tgz YYYYMMDD
rsync -avzP --delete -e ssh YYYYMMDD user@web.sourceforge.net:/home/project-web/mlton/ ↩
    htdocs/guide/
rsync -avzP --delete -e ssh guide-YYYYMMDD.tgz user@web.sourceforge.net:/home/project-web/ ↩
    mlton/htdocs/guide/
```

Announce release

- Mail announcement to:
  - MLton-devel@mlton.org
  - MLton-user@mlton.org

Misc.

- Generate new Performance numbers.

Releases

Public releases of MLton:

- Release20180207
- Release20130715
- Release20100608
- Release20070826
- Release20051202
- Release20041109
- Release20040227
- Release20030716
- Release20030711
- Release20030312
- Release20020923
- Release20020410
- Release20011006
- Release20010806
- Release20010706
- Release20000906
- Release20000712
- Release19990712
- Release19990319
- Release19980826

RemoveUnused

RemoveUnused is an optimization pass for both the SSA and SSA2 IntermediateLanguages, invoked from SSASimplify and SSA2Simplify.

Description

This pass aggressively removes unused:

- datatypes
- datatype constructors
- datatype constructor arguments
- functions
- function arguments
- function returns
- blocks
- block arguments
- statements (variable bindings)
- handlers from non-tail calls (mayRaise analysis)
- continuations from non-tail calls (mayReturn analysis)

Implementation

- `remove-unused.fun`
- `remove-unused2.fun`

Details and Notes

Restore

Restore is a rewrite pass for the SSA and SSA2 IntermediateLanguages, invoked from KnownCase and LocalRef.

Description

This pass restores the SSA condition for a violating SSA or SSA2 program; the program must satisfy:

> Every path from the root to a use of a variable (excluding globals) passes through a def of that variable.

Implementation

- `restore.sig`
- `restore.fun`
- `restore2.sig`
- `restore2.fun`

Details and Notes

Based primarily on Section 19.1 of Modern Compiler Implementation in ML.

The main deviation is the calculation of liveness of the violating variables, which is used to predicate the insertion of phi arguments. This is due to the algorithm's bias towards imperative languages, for which it makes the assumption that all variables are defined in the start block and all variables are "used" at exit.

This is "optimized" for restoration of functions with small numbers of violating variables — use bool vectors to represent sets of violating variables.

Also, we use a `Promise.t` to suspend part of the dominance frontier computation.

ReturnStatement

Programmers coming from languages that have a `return` statement, such as C, Java, and Python, often ask how one can translate functions that return early into SML. This page briefly describes a number of ways to translate uses of `return` to SML.

Conditional iterator function

A conditional iterator function, such as `List.find`, `List.exists`, or `List.all` is probably what you want in most cases. Unfortunately, it might be the case that the particular conditional iteration pattern that you want isn't provided for your data structure. Usually the best alternative in such a case is to implement the desired iteration pattern as a higher-order function. For example, to implement a `find` function for arrays (which already exists as `Array.find`) one could write

```
fun find predicate array = let
   fun loop i =
       if i = Array.length array then
          NONE
       else if predicate (Array.sub (array, i)) then
          SOME (Array.sub (array, i))
       else
          loop (i+1)
in
   loop 0
end
```

Of course, this technique, while probably the most common case in practice, applies only if you are essentially iterating over some data structure.

Escape handler

Probably the most direct way to translate code using `return` statements is to basically implement `return` using exception handling. The mechanism can be packaged into a reusable module with the signature (`exit.sig`):

```
(**
 * Signature for exit (or escape) handlers.
 *
 * Note that the implementation necessarily uses exception handling.  This
 * is to make proper resource handling possible.  Exceptions raised by the
 * implementation can be caught by wildcard exception handlers.  Wildcard
 * exception handlers should generally reraise exceptions after performing
 * their effects.
 *)
signature EXIT = sig
   type 'a t
   (** The type of exits. *)

   val within : ('a t, 'a) CPS.t
   (**
    * Sets up an exit and passes it to the given function.  The function
    * may then return normally or by calling {to} with the exit and a
    * return value.  For example,
    *
    *> Exit.within
    *>    (fn l =>
    *>        if condition then
    *>           Exit.to l 1
    *>        else
    *>           2)
    *
```

```
    * evaluates either to {1} or to {2} depending on the {condition}.
    *
    * Note that the function receiving the exit is called from a non-tail
    * position.
    *)

   val to : 'a t -> 'a -> 'b
   (**
    * {to l v} returns from the {within} invocation that introduced the
    * exit {l} with the value {v}.  Evaluating {to l v} outside of the
    * {within} invocation that introduced {l} is a programming error and
    * raises an exception.
    *
    * Note that the type variable {'b} only appears as the return type.
    * This means that {to} doesn't return normally to the caller and can
    * be called from a context of any type.
    *)

   val call : ('a -> 'b, 'a) CPS.t
   (**
    * Simpler, but less flexibly typed, interface to {within} and {to}.
    * Specifically, {call f} is equivalent to {within (f o to)}.
    *)
end
```

(Typing First-Class Continuations in ML discusses the typing of a related construct.) The implementation (`exit.sml`) is straightforward:

```
structure Exit :> EXIT = struct
   type 'a t = 'a -> exn

   fun within block = let
      exception EscapedExit of 'a
   in
      block EscapedExit
      handle EscapedExit value => value
   end

   fun to exit value = raise exit value

   fun call block = within (block o to)
end
```

Here is an example of how one could implement a `find` function given an `app` function:

```
fun appToFind (app : ('a -> unit) -> 'b -> unit)
              (predicate : 'a -> bool)
              (data : 'b) =
    Exit.call
       (fn return =>
           (app (fn x =>
                    if predicate x then
                       return (SOME x)
                    else
                       ())
                data
          ; NONE))
```

In the above, as soon as the expression `predicate x` evaluates to `true` the `app` invocation is terminated.

Continuation-passing Style (CPS)

A general way to implement complex control patterns is to use CPS. In CPS, instead of returning normally, functions invoke a function passed as an argument. In general, multiple continuation functions may be passed as arguments and the ordinary return continuation may also be used. As an example, here is a function that finds the leftmost element of a binary tree satisfying a given predicate:

```
datatype 'a tree = LEAF | BRANCH of 'a tree * 'a * 'a tree

fun find predicate = let
   fun recurse continue =
       fn LEAF =>
          continue ()
        | BRANCH (lhs, elem, rhs) =>
          recurse
             (fn () =>
                 if predicate elem then
                    SOME elem
                 else
                    recurse continue rhs)
             lhs
in
   recurse (fn () => NONE)
end
```

Note that the above function returns as soon as the leftmost element satisfying the predicate is found.

RSSA

RSSA is an IntermediateLanguage, translated from SSA2 by ToRSSA, optimized by RSSASimplify, and translated by ToMachine to Machine.

Description

RSSA is a IntermediateLanguage that makes representation decisions explicit.

Implementation

- `rssa.sig`
- `rssa.fun`

Type Checking

The new type language is aimed at expressing bit-level control over layout and associated packing of data representations. There are singleton types that denote constants, other atomic types for things like integers and reals, and arbitrary sum types and sequence (tuple) types. The big change to the type system is that type checking is now based on subtyping, not type equality. So, for example, the singleton type `0xFFFFEEBB` whose only inhabitant is the eponymous constant is a subtype of the type `Word32`.

Details and Notes

SSA is an abbreviation for Static Single Assignment. The RSSA IntermediateLanguage is a variant of SSA.

RSSAShrink

RSSAShrink is an optimization pass for the RSSA IntermediateLanguage.

Description

This pass implements a whole family of compile-time reductions, like:

- constant folding, copy propagation
- inline the `Goto` to a block with a unique predecessor

Implementation

- `rssa.fun`

Details and Notes

RSSASimplify

The optimization passes for the RSSA IntermediateLanguage are collected and controlled by the `Backend` functor (`backend.sig`, `backend.fun`).

The following optimization pass is implemented:

- RSSAShrink

The following implementation passes are implemented:

- ImplementHandlers
- ImplementProfiling
- InsertLimitChecks
- InsertSignalChecks

The optimization passes can be controlled from the command-line by the options

- `-diag-pass <pass>` — keep diagnostic info for pass
- `-drop-pass <pass>` — omit optimization pass
- `-keep-pass <pass>` — keep the results of pass

RunningOnAIX

MLton runs fine on AIX.

Also see

- RunningOnPowerPC
- RunningOnPowerPC64

RunningOnAlpha

MLton runs fine on the Alpha architecture.

Notes

- When compiling for Alpha, MLton doesn't support native code generation (`-codegen native`). Hence, performance is not as good as it might be and compile times are longer. Also, the quality of code generated by `gcc` is important. By default, MLton calls `gcc -O1`. You can change this by calling MLton with `-cc-opt -O2`.
- When compiling for Alpha, MLton uses `-align 8` by default.

RunningOnAMD64

MLton runs fine on the AMD64 (aka "x86-64" or "x64") architecture.

Notes

- When compiling for AMD64, MLton targets the 64-bit ABI.
- On AMD64, MLton supports native code generation (`-codegen native` or `-codegen amd64`).
- When compiling for AMD64, MLton uses `-align 8` by default. Using `-align 4` may be incompatible with optimized builds of the GnuMP library, which assume 8-byte alignment. (See the thread at http://www.mlton.org/pipermail/mlton/2009-October/030674.html for more details.)

RunningOnARM

MLton runs fine on the ARM architecture.

Notes

- When compiling for ARM, MLton doesn't support native code generation (`-codegen native`). Hence, performance is not as good as it might be and compile times are longer. Also, the quality of code generated by `gcc` is important. By default, MLton calls `gcc -O1`. You can change this by calling MLton with `-cc-opt -O2`.

RunningOnCygwin

MLton runs on the Cygwin emulation layer, which provides a Posix-like environment while running on Windows. To run MLton with Cygwin, you must first install Cygwin on your Windows machine. To do this, visit the Cygwin site from your Windows machine and run their `setup.exe` script. Then, you can unpack the MLton binary `tgz` in your Cygwin environment.

To run MLton cross-compiled executables on Windows, you must install the Cygwin `dll` on the Windows machine.

Known issues

- Time profiling is disabled.
- Cygwin's `mmap` emulation is less than perfect. Sometimes it interacts badly with `Posix.Process.fork`.
- The `socket.sml` regression test fails. We suspect this is not a bug and is simply due to our test relying on a certain behavior when connecting to a socket that has not yet accepted, which is handled differently on Cygwin than other platforms. Any help in understanding and resolving this issue is appreciated.

Also see

- RunningOnMinGW

RunningOnDarwin

MLton runs fine on Darwin (and on Mac OS X).

Notes

- MLton requires the GnuMP library, which is available via Fink, MacPorts, Homebrew.
- For Intel-based Macs, MLton targets the AMD64 architecture on Darwin 10 (Mac OS X Snow Leopard) and higher and targets the x86 architecture on Darwin 8 (Mac OS X Tiger) and Darwin 9 (Mac OS X Leopard).

Known issues

- Executables that save and load worlds on Darwin 11 (Mac OS X Lion) and higher should be compiled with `-link-opt -fno-PIE` ; see MLtonWorld for more details.
- ProfilingTime may give inaccurate results on multi-processor machines. The `SIGPROF` signal, used to sample the profiled program, is supposed to be delivered 100 times a second (i.e., at 10000us intervals), but there can be delays of over 1 minute between the delivery of consecutive `SIGPROF` signals. A more complete description may be found here and here.

Also see

- RunningOnAMD64
- RunningOnPowerPC
- RunningOnX86

RunningOnFreeBSD

MLton runs fine on FreeBSD.

Notes

- MLton is available as a FreeBSD port.

Known issues

- Executables often run more slowly than on a comparable Linux machine. We conjecture that part of this is due to costs due to heap resizing and kernel zeroing of pages. Any help in solving the problem would be appreciated.
- FreeBSD defaults to a datasize limit of 512M, even if you have more than that amount of memory in the computer. Hence, your MLton process will be limited in the amount of memory it has. To fix this problem, turn up the datasize and the default datasize available to a process: Edit `/boot/loader.conf` to set the limits. For example, the setting

```
kern.maxdsiz="671088640"
kern.dfldsiz="671088640"
kern.maxssiz="134217728"
```

  will give a process 640M of datasize memory, default to 640M available and set 128M of stack size memory.

RunningOnHPPA

MLton runs fine on the HPPA architecture.

Notes

- When compiling for HPPA, MLton targets the 32-bit HPPA architecture.
- When compiling for HPPA, MLton doesn't support native code generation (`-codegen native`). Hence, performance is not as good as it might be and compile times are longer. Also, the quality of code generated by `gcc` is important. By default, MLton calls `gcc -O1`. You can change this by calling MLton with `-cc-opt -O2`.
- When compiling for HPPA, MLton uses `-align 8` by default. While this speeds up reals, it also may increase object sizes. If your program does not make significant use of reals, you might see a speedup with `-align 4`.

RunningOnHPUX

MLton runs fine on HPUX.

Also see

- RunningOnHPPA

RunningOnIA64

MLton runs fine on the IA64 architecture.

Notes

- When compiling for IA64, MLton targets the 64-bit ABI.
- When compiling for IA64, MLton doesn't support native code generation (`-codegen native`). Hence, performance is not as good as it might be and compile times are longer. Also, the quality of code generated by `gcc` is important. By default, MLton calls `gcc -O1`. You can change this by calling MLton with `-cc-opt -O2`.
- When compiling for IA64, MLton uses `-align 8` by default.
- On the IA64, the GnuMP library supports multiple ABIs. See the GnuMP page for more details.

RunningOnLinux

MLton runs fine on Linux.

RunningOnMinGW

MLton runs on MinGW, a library for porting Unix applications to Windows. Some library functionality is missing or changed.

Notes

- To compile MLton on MinGW:
  - The GnuMP library is required.
  - The Bash shell is required. If you are using a prebuilt MSYS, you probably want to symlink `bash` to `sh`.

Known issues

- Many functions are unimplemented and will `raise SysErr`.
  - `MLton.Itimer.set`
  - `MLton.ProcEnv.setgroups`
  - `MLton.Process.kill`
  - `MLton.Process.reap`
  - `MLton.World.load`
  - `OS.FileSys.readLink`
  - `OS.IO.poll`
  - `OS.Process.terminate`
  - `Posix.FileSys.chown`
  - `Posix.FileSys.fchown`
  - `Posix.FileSys.fpathconf`
  - `Posix.FileSys.link`
  - `Posix.FileSys.mkfifo`
  - `Posix.FileSys.pathconf`
  - `Posix.FileSys.readlink`
  - `Posix.FileSys.symlink`
  - `Posix.IO.dupfd`
  - `Posix.IO.getfd`
  - `Posix.IO.getfl`
  - `Posix.IO.getlk`
  - `Posix.IO.setfd`
  - `Posix.IO.setfl`
  - `Posix.IO.setlkw`
  - `Posix.IO.setlk`
  - `Posix.ProcEnv.ctermid`
  - `Posix.ProcEnv.getegid`
  - `Posix.ProcEnv.geteuid`
  - `Posix.ProcEnv.getgid`
  - `Posix.ProcEnv.getgroups`
  - `Posix.ProcEnv.getlogin`

- Posix.ProcEnv.getpgrp
- Posix.ProcEnv.getpid
- Posix.ProcEnv.getppid
- Posix.ProcEnv.getuid
- Posix.ProcEnv.setgid
- Posix.ProcEnv.setpgid
- Posix.ProcEnv.setsid
- Posix.ProcEnv.setuid
- Posix.ProcEnv.sysconf
- Posix.ProcEnv.times
- Posix.ProcEnv.ttyname
- Posix.Process.exece
- Posix.Process.execp
- Posix.Process.exit
- Posix.Process.fork
- Posix.Process.kill
- Posix.Process.pause
- Posix.Process.waitpid_nh
- Posix.Process.waitpid
- Posix.SysDB.getgrgid
- Posix.SysDB.getgrnam
- Posix.SysDB.getpwuid
- Posix.TTY.TC.drain
- Posix.TTY.TC.flow
- Posix.TTY.TC.flush
- Posix.TTY.TC.getattr
- Posix.TTY.TC.getpgrp
- Posix.TTY.TC.sendbreak
- Posix.TTY.TC.setattr
- Posix.TTY.TC.setpgrp
- Unix.kill
- Unix.reap
- UnixSock.fromAddr
- UnixSock.toAddr

RunningOnNetBSD

MLton runs fine on NetBSD.

Installing the correct packages for NetBSD

The NetBSD system installs 3rd party packages by a mechanism known as pkgsrc. This is a tree of Makefiles which when invoked downloads the source code, builds a package and installs it on the system. In order to run MLton on NetBSD, you will have to install several packages for it to work:

- `shells/bash`
- `devel/gmp`
- `devel/gmake`

In order to get graphical call-graphs of profiling information, you will need the additional package

- `graphics/graphviz`

To build the documentation for MLton, you will need the addtional package

- `textproc/asciidoc`.

Tips for compiling and using MLton on NetBSD

MLton can be a memory-hog on computers with little memory. While 640Mb of RAM ought to be enough to self-compile MLton one might want to do some tuning to the NetBSD VM subsystem in order to succeed. The notes presented here is what JesperLouisAndersen uses for compiling MLton on his laptop.

The NetBSD VM subsystem

NetBSD uses a VM subsystem named UVM. Tuning the VM system can be done via the `sysctl(8)`-interface with the "VM" MIB set.

Tuning the NetBSD VM subsystem for MLton

MLton uses a lot of anonymous pages when it is running. Thus, we will need to tune up the default of 80 for anonymous pages. Setting

```
sysctl -w vm.anonmax=95
sysctl -w vm.anonmin=50
sysctl -w vm.filemin=2
sysctl -w vm.execmin=2
sysctl -w vm.filemax=4
sysctl -w vm.execmax=4
```

makes it less likely for the VM system to swap out anonymous pages. For a full explanation of the above flags, see the documentation.

The result is that my laptop goes from a MLton compile where it swaps a lot to a MLton compile with no swapping.

RunningOnOpenBSD

MLton runs fine on OpenBSD.

Known issues

- The `socket.sml` regression test fails. We suspect this is not a bug and is simply due to our test relying on a certain behavior when connecting to a socket that has not yet accepted, which is handled differently on OpenBSD than other platforms. Any help in understanding and resolving this issue is appreciated.

RunningOnPowerPC

MLton runs fine on the PowerPC architecture.

Notes

- When compiling for PowerPC, MLton targets the 32-bit PowerPC architecture.
- When compiling for PowerPC, MLton doesn't support native code generation (`-codegen native`). Hence, performance is not as good as it might be and compile times are longer. Also, the quality of code generated by `gcc` is important. By default, MLton calls `gcc -O1`. You can change this by calling MLton with `-cc-opt -O2`.
- On the PowerPC, the GnuMP library supports multiple ABIs. See the GnuMP page for more details.

RunningOnPowerPC64

MLton runs fine on the PowerPC64 architecture.

Notes

- When compiling for PowerPC64, MLton targets the 64-bit PowerPC architecture.
- When compiling for PowerPC64, MLton doesn't support native code generation (`-codegen native`). Hence, performance is not as good as it might be and compile times are longer. Also, the quality of code generated by `gcc` is important. By default, MLton calls `gcc -O1`. You can change this by calling MLton with `-cc-opt -O2`.
- On the PowerPC64, the GnuMP library supports multiple ABIs. See the GnuMP page for more details.

RunningOnS390

MLton runs fine on the S390 architecture.

Notes

- When compiling for S390, MLton doesn't support native code generation (`-codegen native`). Hence, performance is not as good as it might be and compile times are longer. Also, the quality of code generated by `gcc` is important. By default, MLton calls `gcc -O1`. You can change this by calling MLton with `-cc-opt -O2`.

RunningOnSolaris

MLton runs fine on Solaris.

Notes

- You must install the `binutils`, `gcc`, and `make` packages. You can find out how to get these at sunfreeware.com.
- Making the documentation requires that you install `latex` and `dvips`, which are available in the `tetex` package.

Known issues

- Bootstrapping on the Sparc architecture is so slow as to be impractical (many hours on a 500MHz UltraSparc). For this reason, we strongly recommend building with a cross compiler.

Also see

- RunningOnAMD64
- RunningOnSparc
- RunningOnX86

RunningOnSparc

MLton runs fine on the Sparc architecture.

Notes

- When compiling for Sparc, MLton targets the 32-bit Sparc architecture (i.e., Sparc V8).
- When compiling for Sparc, MLton doesn't support native code generation (`-codegen native`). Hence, performance is not as good as it might be and compile times are longer. Also, the quality of code generated by `gcc` is important. By default, MLton calls `gcc -O1`. You can change this by calling MLton with `-cc-opt -O2`. We have seen this speed up some programs by as much as 30%, especially those involving floating point; however, it can also more than double compile times.
- When compiling for Sparc, MLton uses `-align 8` by default. While this speeds up reals, it also may increase object sizes. If your program does not make significant use of reals, you might see a speedup with `-align 4`.

Known issues

- Bootstrapping on the Sparc architecture is so slow as to be impractical (many hours on a 500MHz UltraSparc). For this reason, we strongly recommend building with a cross compiler.

Also see

- RunningOnSolaris

RunningOnX86

MLton runs fine on the x86 architecture.

Notes

- On x86, MLton supports native code generation (`-codegen native` or `-codegen x86`).

RunTimeOptions

Executables produced by MLton take command line arguments that control the runtime system. These arguments are optional, and occur before the executable's usual arguments. To use these options, the first argument to the executable must be `@MLton`. The optional arguments then follow, must be terminated by `--`, and are followed by any arguments to the program. The optional arguments are *not* made available to the SML program via `CommandLine.arguments`. For example, a valid call to `hello-world` is:

```
hello-world @MLton gc-summary fixed-heap 10k -- a b c
```

In the above example, `CommandLine.arguments () =["a", "b", "c"]`.

It is allowed to have a sequence of `@MLton` arguments, as in:

```
hello-world @MLton gc-summary -- @MLton fixed-heap 10k -- a b c
```

Run-time options can also control MLton, as in

```
mlton @MLton fixed-heap 0.5g -- foo.sml
```

Options

- `fixed-heap` *x*`{k|K|m|M|g|G}`

  Use a fixed size heap of size *x*, where *x* is a real number and the trailing letter indicates its units.

`k` or `K`	1024
`m` or `M`	1,048,576
`g` or `G`	1,073,741,824

  A value of `0` means to use almost all the RAM present on the machine.

  The heap size used by `fixed-heap` includes all memory allocated by SML code, including memory for the stack (or stacks, if there are multiple threads). It does not, however, include any memory used for code itself or memory used by C globals, the C stack, or malloc.

- `gc-messages`

  Print a message at the start and end of every garbage collection.

- `gc-summary`

  Print a summary of garbage collection statistics upon program termination to standard error.

- `gc-summary-file` *file*

  Print a summary of garbage collection statistics upon program termination to the file specified by *file*.

- `load-world` *world*

  Restart the computation with the file specified by *world*, which must have been created by a call to `MLton.World.save` by the same executable. See MLtonWorld.

- `max-heap` *x*`{k|K|m|M|g|G}`

  Run the computation with an automatically resized heap that is never larger than *x*, where *x* is a real number and the trailing letter indicates the units as with `fixed-heap`. The heap size for `max-heap` is accounted for as with `fixed-heap`.

- `may-page-heap {false|true}`

  Enable paging the heap to disk when unable to grow the heap to a desired size.

- `no-load-world`

  Disable `load-world`. This can be used as an argument to the compiler via `-runtime no-load-world` to create executables that will not load a world. This may be useful to ensure that set-uid executables do not load some strange world.

- `ram-slop x`

  Multiply *x* by the amount of RAM on the machine to obtain what the runtime views as the amount of RAM it can use. Typically *x* is less than 1, and is used to account for space used by other programs running on the same machine.

- `stop`

  Causes the runtime to stop processing `@MLton` arguments once the next `--` is reached. This can be used as an argument to the compiler via `-runtime stop` to create executables that don't process any `@MLton` arguments.

ScopeInference

Scope inference is an analysis/rewrite pass for the AST IntermediateLanguage, invoked from Elaborate.

Description

This pass adds free type variables to the `val` or `fun` declaration where they are implicitly scoped.

Implementation

`scope.sig` `scope.fun`

Details and Notes

Scope inference determines for each type variable, the declaration where it is bound. Scope inference is a direct implementation of the specification given in section 4.6 of the Definition. Recall that a free occurrence of a type variable `'a` in a declaration `d` is *unguarded* in `d` if `'a` is not part of a smaller declaration. A type variable `'a` is implicitly scoped at `d` if `'a` is unguarded in `d` and `'a` does not occur unguarded in any declaration containing `d`.

The first pass of scope inference walks down the tree and renames all explicitly bound type variables in order to avoid name collisions. It then walks up the tree and adds to each declaration the set of unguarded type variables occurring in that declaration. At this point, if declaration `d` contains an unguarded type variable `'a` and the immediately containing declaration does not contain `'a`, then `'a` is implicitly scoped at `d`. The final pass walks down the tree leaving a `'a` at the a declaration where it is scoped and removing it from all enclosed declarations.

SelfCompiling

If you want to compile MLton, you must first get the Sources. You can compile with either MLton or SML/NJ, but we strongly recommend using MLton, since it generates a much faster and more robust executable.

Compiling with MLton

To compile with MLton, you need the binary versions of `mlton`, `mllex`, and `mlyacc` that come with the MLton binary package. To be safe, you should use the same version of MLton that you are building. However, older versions may work, as long as they don't go back too far. To build MLton, run `make` from within the root directory of the sources. This will build MLton first with the already installed binary version of MLton and will then rebuild MLton with itself.

First, the `Makefile` calls `mllex` and `mlyacc` to build the lexer and parser, and then calls `mlton` to compile itself. When making MLton using another version the `Makefile` automatically uses `mlton-stubs.mlb`, which will put in enough stubs to emulate the `structure MLton`. Once MLton is built, the `Makefile` will rebuild MLton with itself, this time using `mlton.mlb` and the real `structure MLton` from the Basis Library. This second round of compilation is essential in order to achieve a fast and robust MLton.

Compiling MLton requires at least 1GB of RAM for 32-bit platforms (2GB is preferable) and at least 2GB RAM for 64-bit platforms (4GB is preferable). If your machine has less RAM, self-compilation will likely fail, or at least take a very long time due to paging. Even if you have enough memory, there simply may not be enough available, due to memory consumed by other processes. In this case, you may see an `Out of memory` message, or self-compilation may become extremely slow. The only fix is to make sure that enough memory is available.

Possible Errors

- The C compiler may not be able to find the GnuMP header file, `gmp.h` leading to an error like the following.

  ```
   cenv.h:49:18: fatal error: gmp.h: No such file or directory
  ```

  The solution is to install (or build) GnuMP on your machine. If you install it at a location not on the default seach path, then run `make WITH_GMP_INC_DIR=`*`/path/to/gmp/include`* `WITH_GMP_LIB_DIR=`*`/path/to/gmp/lib`*.

- The following errors indicates that a binary version of MLton could not be found in your path.

  ```
  /bin/sh: mlton: command not found
  ```

  ```
  make[2]: mlton: Command not found
  ```

  You need to have `mlton` in your path to build MLton from source.

  During the build process, there are various times that the `Makefile`-s look for a `mlton` in your path and in `src/build/bin`. It is OK if the latter doesn't exist when the build starts; it is the target being built. Failure to find a `mlton` in your path will abort the build.

Compiling with SML/NJ

To compile with SML/NJ, run `make bootstrap-smlnj` from within the root directory of the sources. You must use a recent version of SML/NJ. First, the `Makefile` calls `ml-lex` and `ml-yacc` to build the lexer and parser. Then, it calls SML/NJ with the appropriate `sources.cm` file. Once MLton is built with SML/NJ, the `Makefile` will rebuild MLton with this SML/NJ built MLton and then will rebuild MLton with the MLton built MLton. Building with SML/NJ takes significant time (particularly during the "`parseAndElaborate`" phase when the SML/NJ built MLton is compiling MLton). Unless you are doing compiler development and need rapid recompilation, we recommend compiling with MLton.

Serialization

Standard ML does not have built-in support for serialization. Here are papers that describe user-level approaches:

- Elsman04
- Kennedy04

The MLton repository also contains an experimental generic programming library (see `README`) that includes a pickling (serialization) generic (see `pickle.sig`).

ShareZeroVec

ShareZeroVec is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

An SSA optimization to share zero-length vectors.

From be8c5f576, which replaced the use of the Array_array0Const primitive in the Basis Library implementation with a (nullary) Vector_vector primitive:

> The original motivation for the Array_array0Const primitive was to share the heap space required for zero-length vectors among all vectors (of a given type). It was claimed that this optimization is important, e.g., in a self-compile, where vectors are used for lots of syntax tree elements and many of those vectors are empty. See: http://www.mlton.org/pipermail/mlton-devel/2002-February/021523.html
>
> Curiously, the full effect of this optimization has been missing for quite some time (perhaps since the port of ConstantPropagation to the SSA IL). While ConstantPropagation has "globalized" the nullary application of the Array_array0Const primitive, it also simultaneously transformed it to an application of the Array_uninit (previously, the Array_array) primitive to the zero constant. The hash-consing of globals, meant to create exactly one global for each distinct constant, treats Array_uninit primitives as unequal (appropriately, since Array_uninit allocates an array with identity (though the identity may be supressed by a subsequent Array_toVector)), hence each distinct Array_array0Const primitive in the program remained as distinct globals. The limited amount of inlining prior to ConstantPropagation meant that there were typically fewer than a dozen "copies" of the same empty vector in a program for a given type.
>
> As a "functional" primitive, a nullary Vector_vector is globalized by ClosureConvert, but is further recognized by ConstantPropagation and hash-consed into a unique instance for each type.

However, a single, shared, global Vector_vector () inhibits the coercion-based optimizations of Useless. For example, consider the following program:

```
val n = valOf (Int.fromString (hd (CommandLine.arguments ())))

val v1 = Vector.tabulate (n, fn i =>
                          let val w = Word16.fromInt i
                          in (w - 0wx1, w, w + 0wx1 + w)
                          end)
val v2 = Vector.map (fn (w1, w2, w3) => (w1, 0wx2 * w2, 0wx3 * w3)) v1
val v3 = VectorSlice.vector (VectorSlice.slice (v1, 1, SOME (n - 2)))
val ans1 = Vector.foldl (fn ((w1,w2,w3),w) => w + w1 + w2 + w3) 0wx0 v1
val ans2 = Vector.foldl (fn ((_,w2,_),w) => w + w2) 0wx0 v2
val ans3 = Vector.foldl (fn ((_,w2,_),w) => w + w2) 0wx0 v3

val _ = print (concat ["ans1 = ", Word16.toString ans1, "  ",
                       "ans2 = ", Word16.toString ans2, "  ",
                       "ans3 = ", Word16.toString ans3, "\n"])
```

We would like v2 and v3 to be optimized from (word16 * word16 * word16) vector to word16 vector because only the 2nd component of the elements is needed to compute the answer.

With Array_array0Const, each distinct occurrence of Array_array0Const((word16 * word16 * word16)) arising from polyvariance and inlining remained a distinct Array_uninit((word16 * word16 * word16)) (0x0) global, which resulted in distinct occurrences for the val v1 =Vector.tabulate ... and for the val v2 =Vector.map .... The latter could be optimized to Array_uninit(word16) (0x0) by Useless, because its result only flows to places requiring the 2nd component of the elements.

With Vector_vector (), the distinct occurrences of Vector_vector((word16 * word16 * word16)) () arising from polyvariance are globalized during ClosureConvert, those global references may be further duplicated by inlining,

but the distinct occurrences of `Vector_vector((word16 * word16 * word16)) ()` are merged to a single occurrence. Because this result flows to places requiring all three components of the elements, it remains `Vector_vector((word16 * word16 * word16)) ()` after `Useless`. Furthermore, because one cannot (in constant time) coerce a `(word16 * word16 * word16) vector` to a `word16 vector`, the `v2` value remains of type `(word16 * word16 * word16) vector`.

One option would be to drop the 0-element vector "optimization" entirely. This costs some space (no sharing of empty vectors) and some time (allocation and garbage collection of empty vectors).

Another option would be to reinstate the `Array_array0Const` primitive and associated `ConstantPropagation` treatment. But, the semantics and purpose of `Array_array0Const` was poorly understood, resulting in this break.

The ShareZeroVec pass pursues a different approach: perform the 0-element vector "optimization" as a separate optimization, after `ConstantPropagation` and `Useless`. A trivial static analysis is used to match `val v:t vector =Array_toVector(t) (a)` with corresponding `val a:array =Array_uninit(t) (l)` and the later are expanded to `val a:t array =if 0 =l then zeroArr_[t] else Array_uninit(t) (l)` with a single global `val zeroArr_[t] =Array_uninit(t) (0)` created for each distinct type (after coercion-based optimizations).

One disadvantage of this approach, compared to the `Vector_vector(t) ()` approach, is that `Array_toVector` is applied each time a vector is created, even if it is being applied to the `zeroArr_[t]` zero-length array. (Although, this was the behavior of the `Array_array0Const` approach.) This updates the object header each time, whereas the `Vector_vector(t) ()` approach would have updated the object header once, when the global was created, and the `zeroVec_[t]` global and the `Array_toVector` result would flow to the join point.

It would be possible to properly share zero-length vectors, but doing so is a more sophisticated analysis and transformation, because there can be arbitrary code between the `val a:t array =Array_uninit(t) (l)` and the corresponding `val v:v vector =Array_toVector(t) (a)`, although, in practice, nothing happens when a zero-length vector is created. It may be best to pursue a more general "array to vector" optimization that transforms creations of static-length vectors (e.g., all the `Vector.new<N>` functions) into `Vector_vector` primitives (some of which could be globalized).

Implementation

- `share-zero-vec.fun`

Details and Notes

ShowBasis

MLton has a flag, `-show-basis <file>`, that causes MLton to pretty print to *file* the basis defined by the input program. For example, if `foo.sml` contains

```
fun f x = x + 1
```

then `mlton -show-basis foo.basis foo.sml` will create `foo.basis` with the following contents.

```
val f: int -> int
```

If you only want to see the basis and do not wish to compile the program, you can call MLton with `-stop tc`.

Displaying signatures

When displaying signatures, MLton prefixes types defined in the signature them with `_sig.` to distinguish them from types defined in the environment. For example,

```
signature SIG =
   sig
      type t
      val x: t * int -> unit
   end
```

is displayed as

```
signature SIG =
   sig
      type t
      val x: _sig.t * int -> unit
   end
```

Notice that `int` occurs without the `_sig.` prefix.

MLton also uses a canonical name for each type in the signature, and that name is used everywhere for that type, no matter what the input signature looked like. For example:

```
signature SIG =
   sig
      type t
      type u = t
      val x: t
      val y: u
   end
```

is displayed as

```
signature SIG =
   sig
      type t
      type u = _sig.t
      val x: _sig.t
      val y: _sig.t
   end
```

Canonical names are always relative to the "top" of the signature, even when used in nested substructures. For example:

```
signature S =
   sig
      type t
      val w: t
      structure U:
         sig
            type u
            val x: t
            val y: u
         end
      val z: U.u
   end
```

is displayed as

```
signature S =
   sig
      type t
      val w: _sig.t
      val z: _sig.U.u
      structure U:
         sig
            type u
            val x: _sig.t
            val y: _sig.U.u
         end
   end
```

Displaying structures

When displaying structures, MLton uses signature constraints wherever possible, combined with `where type` clauses to specify the meanings of the types defined within the signature. For example:

```
signature SIG =
   sig
      type t
      val x: t
   end
structure S: SIG =
   struct
      type t = int
      val x = 13
   end
structure S2:> SIG = S
```

is displayed as

```
signature SIG =
   sig
      type t
      val x: _sig.t
   end
structure S: SIG
             where type t = int
structure S2: SIG
              where type t = S2.t
```

ShowBasisDirective

A comment of the form `(*#showBasis "<file>"*)` is recognized as a directive to save the current basis (i.e., environment) to `<file>` (in the same format as the `-show-basis <file>` compile-time option). The `<file>` is interpreted relative to the source file in which it appears. The comment is lexed as a distinct token and is parsed as a structure-level declaration. [Note that treating the directive as a top-level declaration would prohibit using it inside a functor body, which would make the feature significantly less useful in the context of the MLton compiler sources (with its nearly fully functorial style).]

This feature is meant to facilitate auto-completion via `company-mlton` and similar tools.

ShowProf

If an executable is compiled for profiling, then it accepts a special command-line runtime system argument, `show-prof`, that outputs information about the source functions that are profiled. Normally, this information is used by `mlprof`. This page documents the `show-prof` output format, and is intended for those working on the profiler internals.

The `show-prof` output is ASCII, and consists of a sequence of lines.

- The magic number of the executable.
- The number of source names in the executable.
- A line for each source name giving the name of the function, a tab, the filename of the file containing the function, a colon, a space, and the line number that the function starts on in that file.
- The number of (split) source functions.
- A line for each (split) source function, where each line consists of a source-name index (into the array of source names) and a successors index (into the array of split-source sequences, defined below).
- The number of split-source sequences.
- A line for each split-source sequence, where each line is a space separated list of (split) source functions.

The latter two arrays, split sources and split-source sequences, define a directed graph, which is the call-graph of the program.

Shrink

Shrink is a rewrite pass for the SSA and SSA2 IntermediateLanguages, invoked from every optimization pass (see SSASimplify and SSA2Simplify).

Description

This pass implements a whole family of compile-time reductions, like:

- `#1(a, b)` ⇒ `a`
- `case C x of C y => e` ⇒ `let y =x in e`
- constant folding, copy propagation
- eta blocks
- tuple reconstruction elimination

Implementation

- `shrink.sig`
- `shrink.fun`
- `shrink2.sig`
- `shrink2.fun`

Details and Notes

The Shrink pass is run after every SSA and SSA2 optimization pass.

The Shrink implementation also includes functions to eliminate unreachable blocks from a SSA or SSA2 program or function. The Shrink pass does not guarantee to eliminate all unreachable blocks. Doing so would unduly complicate the implementation, and it is almost always the case that all unreachable blocks are eliminated. However, a small number of optimization passes require that the input have no unreachable blocks (essentially, when the analysis works on the control flow graph and the rewrite iterates on the vector of blocks). These passes explicitly call `eliminateDeadBlocks`.

The Shrink pass has a special case to turn a non-tail call where the continuation and handler only do `Profile` statements into a tail call where the `Profile` statements precede the tail call.

SimplifyTypes

SimplifyTypes is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

This pass computes a "cardinality" of each datatype, which is an abstraction of the number of values of the datatype.

- `Zero` means the datatype has no values (except for bottom).
- `One` means the datatype has one value (except for bottom).
- `Many` means the datatype has many values.

This pass removes all datatypes whose cardinality is `Zero` or `One` and removes:

- components of tuples
- function args
- constructor args

which are such datatypes.

This pass marks constructors as one of:

- `Useless`: it never appears in a `ConApp`.
- `Transparent`: it is the only variant in its datatype and its argument type does not contain any uses of `array` or `vector`.
- `Useful`: otherwise

This pass also removes `Useless` and `Transparent` constructors.

Implementation

- `simplify-types.fun`

Details and Notes

This pass must happen before polymorphic equality is implemented because

- it will make polymorphic equality faster because some types are simpler
- it removes uses of polymorphic equality that must return true

We must keep track of `Transparent` constructors whose argument type uses `array` because of datatypes like the following:

```
datatype t = T of t array
```

Such a datatype has `Cardinality.Many`, but we cannot eliminate the datatype and replace the lhs by the rhs, i.e. we must keep the circularity around.

Must do similar things for `vectors`.

Also, to eliminate as many `Transparent` constructors as possible, for something like the following,

```
datatype t = T of u array
     and u = U of t vector
```

we (arbitrarily) expand one of the datatypes first. The result will be something like

```
datatype u = U of u array array
```

where all uses of `t` are replaced by `u array`.

SML3d

The SML3d Project is a collection of libraries to support 3D graphics programming using Standard ML and the OpenGL graphics API. It currently requires the MLton implementation of SML and is supported on Linux, Mac OS X, and Microsoft Windows. There is also support for OpenCL.

SMLNET

SML.NET is a Standard ML implementation that targets the .NET Common Language Runtime.

SML.NET is based on the MLj compiler.

Also see

- BentonEtAl04

SMLNJ

SML/NJ is a Standard ML implementation. It is a native code compiler that runs on a variety of platforms and has a number of libraries and tools.

We maintain a list of SML/NJ's deviations from The Definition of Standard ML.

MLton has support for some features of SML/NJ in order to ease porting between MLton and SML/NJ.

- CompilationManager (CM)
- LineDirectives
- SMLofNJStructure
- UnsafeStructure

SMLNJDeviations

Here are some deviations of SML/NJ from The Definition of Standard ML (Revised). Some of these are documented in the SML '97 Conversion Guide. Since MLton does not deviate from the Definition, you should look here if you are having trouble porting a program from MLton to SML/NJ or vice versa. If you discover other deviations of SML/NJ that aren't listed here, please send mail to MLton-devel@mlton.org.

- SML/NJ allows spaces in long identifiers, as in `S .x`. Section 2.5 of the Definition implies that `S .x` should be treated as three separate lexical items.
- SML/NJ allows `op` to appear in `val` specifications:

```
signature FOO = sig
   val op + : int * int -> int
end
```

  The grammar on page 14 of the Definition does not allow it. Recent versions of SML/NJ do give a warning.

- SML/NJ rejects

```
(op *)
```

  as an unmatched close comment.

- SML/NJ allows = to be rebound by the declaration:

```
val op = = 13
```

  This is explicitly forbidden on page 5 of the Definition. Recent versions of SML/NJ do give a warning.

- SML/NJ allows rebinding `true`, `false`, `nil`, `::`, and `ref` by the declarations:

```
fun true () = ()
fun false () = ()
fun nil () = ()
fun op :: () = ()
fun ref () = ()
```

  This is explicitly forbidden on page 9 of the Definition.

- SML/NJ extends the syntax of the language to allow vector expressions and patterns like the following:

```
val v = #[1,2,3]
val #[x,y,z] = v
```

  MLton supports vector expressions and patterns with the allowVectorExpsAndPats ML Basis annotation.

- SML/NJ extends the syntax of the language to allow *or patterns* like the following:

```
datatype foo = Foo of int | Bar of int
val (Foo x | Bar x) = Foo 13
```

  MLton supports or patterns with the allowOrPats ML Basis annotation.

- SML/NJ allows higher-order functors, that is, functors can be components of structures and can be passed as functor arguments and returned as functor results. As a consequence, SML/NJ allows abbreviated functor definitions, as in the following:

```
signature S =
  sig
    type t
    val x: t
  end
functor F (structure A: S): S =
```

```
  struct
    type t = A.t * A.t
    val x = (A.x, A.x)
  end
functor G = F
```

- SML/NJ extends the syntax of the language to allow `functor` and `signature` declarations to occur within the scope of `local` and `structure` declarations.
- SML/NJ allows duplicate type specifications in signatures when the duplicates are introduced by `include`, as in the following:

```
signature SIG1 =
   sig
      type t
      type u
   end
signature SIG2 =
   sig
      type t
      type v
   end
signature SIG =
   sig
      include SIG1
      include SIG2
   end
```

  This is disallowed by rule 77 of the Definition.

- SML/NJ allows sharing constraints between type abbreviations in signatures, as in the following:

```
signature SIG =
   sig
      type t = int * int
      type u = int * int
      sharing type t = u
   end
```

  These are disallowed by rule 78 of the Definition. Recent versions of SML/NJ correctly disallow sharing constraints between type abbreviations in signatures.

- SML/NJ disallows multiple `where type` specifications of the same type name, as in the following

```
signature S =
  sig
     type t
     type u = t
  end
  where type u = int
```

  This is allowed by rule 64 of the Definition.

- SML/NJ allows `and` in `sharing` specs in signatures, as in

```
signature S =
   sig
      type t
      type u
      type v
      sharing type t = u
      and type u = v
   end
```

- SML/NJ does not expand the `withtype` derived form as described by the Definition. According to page 55 of the Definition, the type bindings of a `withtype` declaration are substituted simultaneously in the connected datatype. Consider the following program.

```
type u = real ;
datatype a =
    A of t
  | B of u
withtype u = int
and t = u
```

  According to the Definition, it should be expanded to the following.

```
type u = real ;
datatype a =
    A of u
  | B of int ;
type u = int
and t = u
```

  However, SML/NJ expands `withtype` bindings sequentially, meaning that earlier bindings are expanded within later ones. Hence, the above program is expanded to the following.

```
type u = real ;
datatype a =
    A of int
  | B of int ;
type u = int
type t = int
```

- SML/NJ allows `withtype` specifications in signatures.

  MLton supports `withtype` specifications in signatures with the allowSigWithtype ML Basis annotation.

- SML/NJ allows a `where` structure specification that is similar to a `where type` specification. For example:

```
structure S = struct type t = int end
signature SIG =
  sig
     structure T : sig type t end
  end where T = S
```

  This is equivalent to:

```
structure S = struct type t = int end
signature SIG =
  sig
     structure T : sig type t end
  end where type T.t = S.t
```

  SML/NJ also allows a definitional structure specification that is similar to a definitional type specification. For example:

```
structure S = struct type t = int end
signature SIG =
  sig
     structure T : sig type t end = S
  end
```

  This is equivalent to the previous examples and to:

```
structure S = struct type t = int end
signature SIG =
  sig
     structure T : sig type t end where type t = S.t
  end
```

- SML/NJ disallows binding non-datatypes with datatype replication. For example, it rejects the following program that should be allowed according to the Definition.

```
type ('a, 'b) t = 'a * 'b
datatype u = datatype t
```

  This idiom can be useful when one wants to rename a type without rewriting all the type arguments. For example, the above would have to be written in SML/NJ as follows.

```
type ('a, 'b) t = 'a * 'b
type ('a, 'b) u = ('a, 'b) t
```

- SML/NJ disallows sharing a structure with one of its substructures. For example, SML/NJ disallows the following.

```
signature SIG =
   sig
      structure S:
         sig
            type t
            structure T: sig type t end
         end
      sharing S = S.T
   end
```

  This signature is allowed by the Definition.

- SML/NJ disallows polymorphic generalization of refutable patterns. For example, SML/NJ disallows the following.

```
val [x] = [[]]
val _ = (1 :: x, "one" :: x)
```

  Recent versions of SML/NJ correctly allow polymorphic generalization of refutable patterns.

- SML/NJ uses an overly restrictive context for type inference. For example, SML/NJ rejects both of the following.

```
structure S =
struct
  val z = (fn x => x) []
  val y = z :: [true] :: nil
end
```

```
structure S : sig val z : bool list end =
struct
  val z = (fn x => x) []
end
```

  These structures are allowed by the Definition.

Deviations from the Basis Library Specification

Here are some deviations of SML/NJ from the Basis Library specification.

- SML/NJ exposes the equality of the `vector` type in structures such as `Word8Vector` that abstractly match `MONO_VECTOR`, which says `type vector`, not `eqtype vector`. So, for example, SML/NJ accepts the following program:

```
fun f (v: Word8Vector.vector) = v = v
```

- SML/NJ exposes the equality property of the type `status` in `OS.Process`. This means that programs which directly compare two values of type `status` will work with SML/NJ but not MLton.

* Under SML/NJ on Windows, `OS.Path.validVolume` incorrectly considers absolute empty volumes to be valid. In other words, when the expression

  ```
  OS.Path.validVolume { isAbs = true, vol = "" }
  ```

  is evaluated by SML/NJ on Windows, the result is `true`. MLton, on the other hand, correctly follows the Basis Library Specification, which states that on Windows, `OS.Path.validVolume` should return `false` whenever `isAbs =true` and `vol =""`.

  This incorrect behavior causes other `OS.Path` functions to behave differently. For example, when the expression

  ```
  OS.Path.toString (OS.Path.fromString "\\usr\\local")
  ```

  is evaluated by SML/NJ on Windows, the result is `"\\usr\\local"`, whereas under MLton on Windows, evaluating this expression (correctly) causes an `OS.Path.Path` exception to be raised.

SMLNJLibrary

The SML/NJ Library is a collection of libraries that are distributed with SML/NJ. Due to differences between SML/NJ and MLton, these libraries will not work out-of-the box with MLton.

As of 20180119, MLton includes a port of the SML/NJ Library synchronized with SML/NJ version 110.82.

Usage

- You can import a sub-library of the SML/NJ Library into an MLB file with:

MLB file	Description
`$(SML_LIB)/smlnj-lib/Util/smlnj-lib.mlb`	Various utility modules, included collections, simple formating, . . .
`$(SML_LIB)/smlnj-lib/Controls/controls-lib.mlb`	A library for managing control flags in an application.
`$(SML_LIB)/smlnj-lib/HashCons/hash-cons-lib.mlb`	Support for implementing hash-consed data structures.
`$(SML_LIB)/smlnj-lib/HTML/html-lib.mlb`	HTML 3.2 parsing and pretty-printing library.
`$(SML_LIB)/smlnj-lib/HTML4/html4-lib.mlb`	HTML 4.01 parsing and pretty-printing library.
`$(SML_LIB)/smlnj-lib/INet/inet-lib.mlb`	Networking utilities; supported on both Unix and Windows systems.
`$(SML_LIB)/smlnj-lib/JSON/json-lib.mlb`	JavaScript Object Notation (JSON) reading and writing library.
`$(SML_LIB)/smlnj-lib/PP/pp-lib.mlb`	Pretty-printing library.
`$(SML_LIB)/smlnj-lib/Reactive/reactive-lib.mlb`	Reactive scripting library.
`$(SML_LIB)/smlnj-lib/RegExp/regexp-lib.mlb`	Regular expression library.
`$(SML_LIB)/smlnj-lib/SExp/sexp-lib.mlb`	S-expression library.
`$(SML_LIB)/smlnj-lib/Unix/unix-lib.mlb`	Utilities for Unix-based operating systems.
`$(SML_LIB)/smlnj-lib/XML/xml-lib.mlb`	XML library.

- If you are porting a project from SML/NJ's CompilationManager to MLton's ML Basis system using `cm2mlb`, note that the following maps are included by default:

```
# SMLNJ Library
$SMLNJ-LIB                              $(SML_LIB)/smlnj-lib
$smlnj-lib.cm                           $(SML_LIB)/smlnj-lib/Util
$controls-lib.cm                        $(SML_LIB)/smlnj-lib/Controls
$hash-cons-lib.cm                       $(SML_LIB)/smlnj-lib/HashCons
$html-lib.cm                            $(SML_LIB)/smlnj-lib/HTML
$html4-lib.cm                           $(SML_LIB)/smlnj-lib/HTML4
$inet-lib.cm                            $(SML_LIB)/smlnj-lib/INet
$json-lib.cm                            $(SML_LIB)/smlnj-lib/JSON
$pp-lib.cm                              $(SML_LIB)/smlnj-lib/PP
$reactive-lib.cm                        $(SML_LIB)/smlnj-lib/Reactive
$regexp-lib.cm                          $(SML_LIB)/smlnj-lib/RegExp
$sexp-lib.cm                            $(SML_LIB)/smlnj-lib/SExp
$unix-lib.cm                            $(SML_LIB)/smlnj-lib/Unix
$xml-lib.cm                             $(SML_LIB)/smlnj-lib/XML
```

This will automatically convert a `$/smlnj-lib.cm` import in an input `.cm` file into a `$(SML_LIB)/smlnj-lib/Util/smlnj-lib.mlb` import in the output `.mlb` file.

Details

The following changes were made to the SML/NJ Library, in addition to deriving the `.mlb` files from the `.cm` files:

- `HTML4/pp-init.sml` (added): Implements `structure PrettyPrint` using the SML/NJ PP Library. This implementation is taken from the SML/NJ compiler source, since the SML/NJ HTML4 Library used the `structure PrettyPrint` provided by the SML/NJ compiler itself.
- `Util/base64.sml` (modified): Rewrote use of `Unsafe.CharVector.create` and `Unsafe.CharVector.update`; MLton assumes that vectors are immutable.
- `Util/engine.mlton.sml` (added, not exported): Implements `structure Engine`, providing time-limited, resumable computations using MLtonThread, MLtonSignal, and MLtonItimer.
- `Util/graph-scc-fn.sml` (modified): Rewrote use of `where` structure specification.
- `Util/redblack-map-fn.sml` (modified): Rewrote use of `where` structure specification.
- `Util/redblack-set-fn.sml` (modified): Rewrote use of `where` structure specification.
- `Util/time-limit.mlb` (added): Exports `structure TimeLimit`, which is *not* exported by `smlnj-lib.mlb`. Since MLton is very conservative in the presence of threads and signals, program performance may be adversely affected by unnecessarily including `structure TimeLimit`.
- `Util/time-limit.mlton.sml` (added): Implements `structure TimeLimit` using `structure Engine`. The SML/NJ implementation of `structure TimeLimit` uses SML/NJ's first-class continuations, signals, and interval timer.

Patch

- `smlnj-lib.patch`

SMLofNJStructure

```
signature SML_OF_NJ =
   sig
      structure Cont:
         sig
            type 'a cont
            val callcc: ('a cont -> 'a) -> 'a
            val isolate: ('a -> unit) -> 'a cont
            val throw: 'a cont -> 'a -> 'b
         end
      structure SysInfo:
         sig
            exception UNKNOWN
            datatype os_kind = BEOS | MACOS | OS2 | UNIX | WIN32

            val getHostArch: unit -> string
            val getOSKind: unit -> os_kind
            val getOSName: unit -> string
         end

      val exnHistory: exn -> string list
      val exportFn: string * (string * string list -> OS.Process.status) -> unit
      val exportML: string -> bool
      val getAllArgs: unit -> string list
      val getArgs: unit -> string list
      val getCmdName: unit -> string
   end
```

`SMLofNJ` implements a subset of the structure of the same name provided in Standard ML of New Jersey. It is included to make it easier to port programs between the two systems. The semantics of these functions may be different than in SML/NJ.

- `structure Cont`

  implements continuations.

- `SysInfo.getHostArch ()`

  returns the string for the architecture.

- `SysInfo.getOSKind`

  returns the OS kind.

- `SysInfo.getOSName ()`

  returns the string for the host.

- `exnHistory`

  the same as `MLton.Exn.history`.

- `getCmdName ()`

  the same as `CommandLine.name ()`.

- `getArgs ()`

  the same as `CommandLine.arguments ()`.

- `getAllArgs ()`

  the same as `getCmdName()::getArgs()`.

- `exportFn f`

  saves the state of the computation to a file that will apply `f` to the command-line arguments upon restart.

- `exportML f`

  saves the state of the computation to file `f` and continue. Returns `true` in the restarted computation and `false` in the continuing computation.

SMLSharp

SML# is an implementation of an extension of SML.

It includes some generally useful SML tools including a pretty printer generator, a document generator, and a regression testing framework, and scripting library.

Sources

We maintain our sources with Git. You can view them on the web or access them with a git client.

Anonymous read-only access is available via

```
https://github.com/MLton/mlton.git
```

or

```
git://github.com/MLton/mlton.git
```

Commit email

All commits are sent to `MLton-commit@mlton.org` (subscribe, archive, archive) which is a read-only mailing list for commit emails. Discussion should go to `MLton-devel@mlton.org`.

Changelog

See `CHANGELOG.adoc` for a list of changes and bug fixes.

Subversion

Prior to 20130308, we used Subversion.

CVS

Prior to 20050730, we used CVS.

SpaceSafety

Informally, space safety is a property of a language implementation that asymptotically bounds the space used by a running program.

Also see

- Chapter 12 of Appel92
- Clinger98

SSA

SSA is an IntermediateLanguage, translated from SXML by ClosureConvert, optimized by SSASimplify, and translated by ToSSA2 to SSA2.

Description

SSA is a FirstOrder, SimplyTyped IntermediateLanguage. It is the main IntermediateLanguage used for optimizations.

An SSA program consists of a collection of datatype declarations, a sequence of global statements, and a collection of functions, along with a distinguished "main" function. Each function consists of a collection of basic blocks, where each basic block is a sequence of statements ending with some control transfer.

Implementation

- `ssa.sig`
- `ssa.fun`
- `ssa-tree.sig`
- `ssa-tree.fun`

Type Checking

Type checking (`type-check.sig`, `type-check.fun`) of a SSA program verifies the following:

- no duplicate definitions (tycons, cons, vars, labels, funcs)
- no out of scope references (tycons, cons, vars, labels, funcs)
- variable definitions dominate variable uses
- case transfers are exhaustive and irredundant
- `Enter`/`Leave` profile statements match
- "traditional" well-typedness

Details and Notes

SSA is an abbreviation for Static Single Assignment.

For some initial design discussion, see the thread at:

- http://mlton.org/pipermail/mlton/2001-August/019689.html

For some retrospectives, see the threads at:

- http://mlton.org/pipermail/mlton/2003-January/023054.html
- http://mlton.org/pipermail/mlton/2007-February/029597.html

SSA2

SSA2 is an IntermediateLanguage, translated from SSA by ToSSA2, optimized by SSA2Simplify, and translated by ToRSSA to RSSA.

Description

SSA2 is a FirstOrder, SimplyTyped IntermediateLanguage, a slight variant of the SSA IntermediateLanguage,

Like SSA, an SSA2 program consists of a collection of datatype declarations, a sequence of global statements, and a collection of functions, along with a distinguished "main" function. Each function consists of a collection of basic blocks, where each basic block is a sequence of statements ending with some control transfer.

Unlike SSA, SSA2 includes mutable fields in objects and makes the vector type constructor n-ary instead of unary. This allows optimizations like RefFlatten and DeepFlatten to be expressed.

Implementation

- `ssa2.sig`
- `ssa2.fun`
- `ssa-tree2.sig`
- `ssa-tree2.fun`

Type Checking

Type checking (`type-check2.sig`, `type-check2.fun`) of a SSA2 program verifies the following:

- no duplicate definitions (tycons, cons, vars, labels, funcs)
- no out of scope references (tycons, cons, vars, labels, funcs)
- variable definitions dominate variable uses
- case transfers are exhaustive and irredundant
- `Enter`/`Leave` profile statements match
- "traditional" well-typedness

Details and Notes

SSA is an abbreviation for Static Single Assignment.

SSA2Simplify

The optimization passes for the SSA2 IntermediateLanguage are collected and controlled by the `Simplify2` functor (`simplify2.sig`, `simplify2.fun`).

The following optimization passes are implemented:

- DeepFlatten
- RefFlatten
- RemoveUnused
- Zone

There are additional analysis and rewrite passes that augment many of the other optimization passes:

- Restore
- Shrink

The optimization passes can be controlled from the command-line by the options

- `-diag-pass <pass>` — keep diagnostic info for pass
- `-disable-pass <pass>` — skip optimization pass (if normally performed)
- `-enable-pass <pass>` — perform optimization pass (if normally skipped)
- `-keep-pass <pass>` — keep the results of pass
- `-loop-passes <n>` — loop optimization passes
- `-ssa2-passes <passes>` — ssa optimization passes

SSASimplify

The optimization passes for the SSA IntermediateLanguage are collected and controlled by the `Simplify` functor (`simplify.sig`, `simplify.fun`).

The following optimization passes are implemented:

- CombineConversions
- CommonArg
- CommonBlock
- CommonSubexp
- ConstantPropagation
- Contify
- Flatten
- Inline
- IntroduceLoops
- KnownCase
- LocalFlatten
- LocalRef
- LoopInvariant
- LoopUnfoll
- LoopUnswitch
- Redundant
- RedundantTests
- RemoveUnused
- ShareZeroVec
- SimplifyTypes
- Useless

The following implementation passes are implemented:

- PolyEqual
- PolyHash

There are additional analysis and rewrite passes that augment many of the other optimization passes:

- Multi
- Restore
- Shrink

The optimization passes can be controlled from the command-line by the options:

- `-diag-pass <pass>` — keep diagnostic info for pass
- `-disable-pass <pass>` — skip optimization pass (if normally performed)
- `-enable-pass <pass>` — perform optimization pass (if normally skipped)
- `-keep-pass <pass>` — keep the results of pass
- `-loop-passes <n>` — loop optimization passes
- `-ssa-passes <passes>` — ssa optimization passes

Stabilizers

Installation

- Stabilizers currently require the MLton sources, this should be fixed by the next release

License

- Stabilizers are released under the MLton License

Instructions

- Download and build a source copy of MLton
- Extract the tar.gz file attached to this page
- Some examples are provided in the "examples/" sub directory, more examples will be added to this page in the following week

Bug reports / Suggestions

- Please send any errors you encounter to schatzp and lziarek at cs.purdue.edu
- We are looking to expand the usability of stabilizers
- Please send any suggestions and desired functionality to the above email addresses

Note

- This is an alpha release. We expect to have another release shortly with added functionality soon
- More documentation, such as signatures and descriptions of functionality, will be forthcoming

Documentation

```
signature STABLE =
  sig
     type checkpoint

     val stable: ('a -> 'b) -> ('a -> 'b)
     val stabilize: unit -> 'a

     val stableCP: (('a -> 'b) * (unit -> unit)) ->
                   (('a -> 'b) *  checkpoint)
     val stabilizeCP: checkpoint -> unit

     val unmonitoredAssign: ('a ref * 'a) -> unit
     val monitoredAssign: ('a ref * 'a) -> unit
  end
```

`Stable` provides functions to manage stable sections.

- `type checkpoint`

  handle used to stabilize contexts other than the current one.

- `stable f`

  returns a function identical to `f` that will execute within a stable section.

- `stabilize ()`

  unrolls the effects made up to the current context to at least the nearest enclosing *stable* section. These effects may have propagated to other threads, so all affected threads are returned to a globally consistent previous state. The return is undefined because control cannot resume after stabilize is called.

- `stableCP (f, comp)`

  returns a function `f'` and checkpoint tag `cp`. Function `f'` is identical to `f` but when applied will execute within a stable section. `comp` will be executed if `f'` is later stabilized. `cp` is used by `stabilizeCP` to stabilize a given checkpoint.

- `stabilizeCP cp`

  same as stabilize except that the (possibly current) checkpoint to stabilize is provided.

- `unmonitoredAssign (r, v)`

  standard assignment (`:=`). The version of CML distributed rebinds `:=` to a monitored version so interesting effects can be recorded.

- `monitoredAssign (r, v)`

  the assignment operator that should be used in programs that use stabilizers. `:=` is rebound to this by including CML.

Download

- `stabilizers_alpha_2006-10-09.tar.gz`

Also see

- ZiarekEtAl06

StandardML

Standard ML (SML) is a programming language that combines excellent support for rapid prototyping, modularity, and development of large programs, with performance approaching that of C.

SML Resources

- Tutorials
- Books
- Implementations

Aspects of SML

- DefineTypeBeforeUse
- EqualityType
- EqualityTypeVariable
- GenerativeDatatype
- GenerativeException
- Identifier
- OperatorPrecedence
- Overloading
- PolymorphicEquality
- TypeVariableScope
- ValueRestriction

Using SML

- Fixpoints
- ForLoops
- FunctionalRecordUpdate
- InfixingOperators
- Lazy
- ObjectOrientedProgramming
- OptionalArguments
- Printf
- PropertyList
- ReturnStatement
- Serialization
- StandardMLGotchas
- StyleGuide
- TipsForWritingConciseSML
- UniversalType

Programming in SML

- Emacs
- Enscript
- Pygments

Notes

- History of SML
- Regions

Related Languages

- Alice
- F#
- OCaml

StandardMLBooks

Introductory Books

- Elements of ML Programming
- ML For the Working Programmer
- Introduction to Programming using SML
- The Little MLer

Applications

- Unix System Programming with Standard ML

Reference Books

- The Standard ML Basis Library
- The Definition of Standard ML (Revised)

Related Topics

- Concurrent Programming in ML
- Purely Functional Data Structures

StandardMLGotchas

This page contains brief explanations of some recurring sources of confusion and problems that SML newbies encounter.

Many confusions about the syntax of SML seem to arise from the use of an interactive REPL (Read-Eval Print Loop) while trying to learn the basics of the language. While writing your first SML programs, you should keep the source code of your programs in a form that is accepted by an SML compiler as a whole.

The and keyword

It is a common mistake to misuse the and keyword or to not know how to introduce mutually recursive definitions. The purpose of the and keyword is to introduce mutually recursive definitions of functions and datatypes. For example,

```
fun isEven 0w0 = true
  | isEven 0w1 = false
  | isEven n = isOdd (n-0w1)
and isOdd 0w0 = false
  | isOdd 0w1 = true
  | isOdd n = isEven (n-0w1)
```

and

```
datatype decl = VAL of id * pat * expr
           (* | ... *)
     and expr = LET of decl * expr
           (* | ... *)
```

You can also use and as a shorthand in a couple of other places, but it is not necessary.

Constructed patterns

It is a common mistake to forget to parenthesize constructed patterns in fun bindings. Consider the following invalid definition:

```
fun length nil = 0
  | length h :: t = 1 + length t
```

The pattern `h
t` needs to be parenthesized:

```
fun length nil = 0
  | length (h :: t) = 1 + length t
```

The parentheses are needed, because a fun definition may have multiple consecutive constructed patterns through currying.

The same applies to nonfix constructors. For example, the parentheses in

```
fun valOf NONE = raise Option
  | valOf (SOME x) = x
```

are required. However, the outermost constructed pattern in a fn or case expression need not be parenthesized, because in those cases there is always just one constructed pattern. So, both

```
val valOf = fn NONE => raise Option
             | SOME x => x
```

and

```
fun valOf x = case x of
                NONE => raise Option
              | SOME x => x
```

are fine.

Declarations and expressions

It is a common mistake to confuse expressions and declarations. Normally an SML source file should only contain declarations. The following are declarations:

```
datatype dt = ...
fun f ... = ...
functor Fn (...) = ...
infix ...
infixr ...
local ... in ... end
nonfix ...
open ...
signature SIG = ...
structure Struct = ...
type t = ...
val v = ...
```

Note that

```
let ... in ... end
```

isn't a declaration.

To specify a side-effecting computation in a source file, you can write:

```
val () = ...
```

Equality types

SML has a fairly intricate built-in notion of equality. See EqualityType and EqualityTypeVariable for a thorough discussion.

Nested cases

It is a common mistake to write nested case expressions without the necessary parentheses. See UnresolvedBugs for a discussion.

(op *)

It used to be a common mistake to parenthesize `op *` as `(op *)`. Before SML'97, `*)` was considered a comment terminator in SML and caused a syntax error. At the time of writing, SML/NJ still rejects the code. An extra space may be used for portability: `(op * )`. However, parenthesizing `op` is redundant, even though it is a widely used convention.

Overloading

A number of standard operators (`+`, `-`, `~`, `*`, `<`, `>`, `...`) and numeric constants are overloaded for some of the numeric types (`int`, `real`, `word`). It is a common surprise that definitions using overloaded operators such as

```
fun min (x, y) = if y < x then y else x
```

are not overloaded themselves. SML doesn't really support (user-defined) overloading or other forms of ad hoc polymorphism. In cases such as the above where the context doesn't resolve the overloading, expressions using overloaded operators or constants get assigned a default type. The above definition gets the type

```
val min : int * int -> int
```

See Overloading and TypeIndexedValues for further discussion.

Semicolons

It is a common mistake to use redundant semicolons in SML code. This is probably caused by the fact that in an SML REPL, a semicolon (and enter) is used to signal the REPL that it should evaluate the preceding chunk of code as a unit. In SML source files, semicolons are really needed in only two places. Namely, in expressions of the form

```
(exp ; ... ; exp)
```

and

```
let ... in exp ; ... ; exp end
```

Note that semicolons act as expression (or declaration) separators rather than as terminators.

Stale bindings

Unresolved records

Value restriction

See ValueRestriction.

Type Variable Scope

See TypeVariableScope.

StandardMLHistory

Standard ML grew out of ML in the early 1980s.

For an excellent overview of SML's history, see Appendix F of the Definition.

For an overview if its history before 1982, see How ML Evolved.

StandardMLImplementations

There are a number of implementations of Standard ML, from interpreters, to byte-code compilers, to incremental compilers, to whole-program compilers.

- Alice ML
- HaMLet
- ML Kit
- MLton
- Moscow ML
- Poly/ML
- SML#
- SML/NJ
- SML.NET
- TILT

Not Actively Maintained

- Edinburgh ML
- MLj
- MLWorks
- Poplog
- TIL

StandardMLPortability

Technically, SML'97 as defined in the Definition requires only a minimal initial basis, which, while including the types `int`, `real`, `char`, and `string`, need have no operations on those base types. Hence, the only observable output of an SML'97 program is termination or raising an exception. Most SML compilers should agree there, to the degree each agrees with the Definition. See UnresolvedBugs for MLton's very few corner cases.

Realistically, a program needs to make use of the Basis Library. Within the Basis Library, there are numerous places where the behavior is implementation dependent. For a trivial example:

```
val _ = valOf (Int.maxInt)
```

may either raise the `Option` exception (if `Int.maxInt ==NONE`) or may terminate normally. The default Int/Real/Word sizes are the biggest implementation dependent aspect; so, one implementation may raise `Overflow` while another can accommodate the result. Also, maximum array and vector lengths are implementation dependent. Interfacing with the operating system is a bit murky, and implementations surely differ in handling of errors there.

StandardMLTutorials

- A Gentle Introduction to ML. Andrew Cummings.
- Programming in Standard ML '97: An Online Tutorial. Stephen Gilmore.
- Programming in Standard ML. Robert Harper.
- Essentials of Standard ML Modules. Mads Tofte.
- Tips for Computer Scientists on Standard ML (Revised). Mads Tofte.

StaticSum

While SML makes it impossible to write functions whose types would depend on the values of their arguments, or so called dependently typed functions, it is possible, and arguably commonplace, to write functions whose types depend on the types of their arguments. Indeed, the types of parametrically polymorphic functions like `map` and `foldl` can be said to depend on the types of their arguments. What is less commonplace, however, is to write functions whose behavior would depend on the types of their arguments. Nevertheless, there are several techniques for writing such functions. Type-indexed values and fold are two such techniques. This page presents another such technique dubbed static sums.

Ordinary Sums

Consider the sum type as defined below:

```
structure Sum = struct
   datatype ('a, 'b) t = INL of 'a | INR of 'b
end
```

While a generic sum type such as defined above is very useful, it has a number of limitations. As an example, we could write the function `out` to extract the value from a sum as follows:

```
fun out (s : ('a, 'a) Sum.t) : 'a =
    case s
     of Sum.INL a => a
      | Sum.INR a => a
```

As can be seen from the type of `out`, it is limited in the sense that it requires both variants of the sum to have the same type. So, `out` cannot be used to extract the value of a sum of two different types, such as the type `(int, real) Sum.t`. As another example of a limitation, consider the following attempt at a `succ` function:

```
fun succ (s : (int, real) Sum.t) : ??? =
    case s
     of Sum.INL i => i + 1
      | Sum.INR r => Real.nextAfter (r, Real.posInf)
```

The above definition of `succ` cannot be typed, because there is no type for the codomain within SML.

Static Sums

Interestingly, it is possible to define values `inL`, `inR`, and `match` that satisfy the laws

```
match (inL x) (f, g) = f x
match (inR x) (f, g) = g x
```

and do not suffer from the same limitions. The definitions are actually quite trivial:

```
structure StaticSum = struct
   fun inL x (f, _) = f x
   fun inR x (_, g) = g x
   fun match x = x
end
```

Now, given the `succ` function defined as

```
fun succ s =
    StaticSum.match s
       (fn i => i + 1,
        fn r => Real.nextAfter (r, Real.posInf))
```

we get

```
succ (StaticSum.inL 1) = 2
succ (StaticSum.inR Real.maxFinite) = Real.posInf
```

To better understand how this works, consider the following signature for static sums:

```
structure StaticSum :> sig
   type ('dL, 'cL, 'dR, 'cR, 'c) t
   val inL : 'dL -> ('dL, 'cL, 'dR, 'cR, 'cL) t
   val inR : 'dR -> ('dL, 'cL, 'dR, 'cR, 'cR) t
   val match : ('dL, 'cL, 'dR, 'cR, 'c) t -> ('dL -> 'cL) * ('dR -> 'cR) -> 'c
end = struct
   type ('dL, 'cL, 'dR, 'cR, 'c) t = ('dL -> 'cL) * ('dR -> 'cR) -> 'c
   open StaticSum
end
```

Above, `'d` stands for domain and `'c` for codomain. The key difference between an ordinary sum type, like `(int, real) Sum.t`, and a static sum type, like `(int, real, real, int, real) StaticSum.t`, is that the ordinary sum type says nothing about the type of the result of deconstructing a sum while the static sum type specifies the type.

With the sealed static sum module, we get the type

```
val succ : (int, int, real, real, 'a) StaticSum.t -> 'a
```

for the previously defined `succ` function. The type specifies that `succ` maps a left `int` to an `int` and a right `real` to a `real`. For example, the type of `StaticSum.inL 1` is `(int, 'cL, 'dR, 'cR, 'cL) StaticSum.t`. Unifying this with the argument type of `succ` gives the type `(int, int, real, real, int) StaticSum.t -> int`.

The `out` function is quite useful on its own. Here is how it can be defined:

```
structure StaticSum = struct
   open StaticSum
   val out : ('a, 'a, 'b, 'b, 'c) t -> 'c =
    fn s => match s (fn x => x, fn x => x)
end
```

Due to the value restriction, lack of first class polymorphism and polymorphic recursion, the usefulness and convenience of static sums is somewhat limited in SML. So, don't throw away the ordinary sum type just yet. Static sums can nevertheless be quite useful.

Example: Send and Receive with Argument Type Dependent Result Types

In some situations it would seem useful to define functions whose result type would depend on some of the arguments. Traditionally such functions have been thought to be impossible in SML and the solution has been to define multiple functions. For example, the `Socket` structure of the Basis library defines 16 `send` and 16 `recv` functions. In contrast, the Net structure (`net.sig`) of the Basic library designed by Stephen Weeks defines only a single `send` and a single `receive` and the result types of the functions depend on their arguments. The implementation (`net.sml`) uses static sums (with a slighly different signature: `static-sum.sig`).

Example: Picking Monad Results

Suppose that we need to write a parser that accepts a pair of integers and returns their sum given a monadic parsing combinator library. A part of the signature of such library could look like this

```
signature PARSING = sig
   include MONAD
   val int : int t
   val lparen : unit t
   val rparen : unit t
```

```
   val comma : unit t
   (* ... *)
end
```

where the `MONAD` signature could be defined as

```
signature MONAD = sig
   type 'a t
   val return : 'a -> 'a t
   val >>= : 'a t * ('a -> 'b t) -> 'b t
end
infix >>=
```

The straightforward, but tedious, way to write the desired parser is:

```
val p = lparen >>= (fn _ =>
        int    >>= (fn x =>
        comma  >>= (fn _ =>
        int    >>= (fn y =>
        rparen >>= (fn _ =>
        return (x + y))))))
```

In Haskell, the parser could be written using the `do` notation considerably less verbosely as:

```
p = do { lparen ; x <- int ; comma ; y <- int ; rparen ; return $ x + y }
```

SML doesn't provide a `do` notation, so we need another solution.

Suppose we would have a "pick" notation for monads that would allows us to write the parser as

```
val p = `lparen ^ \int ^ `comma ^ \int ^ `rparen @ (fn x & y => x + y)
```

using four auxiliary combinators: `` ` ``, `\`, `^`, and `@`.

Roughly speaking

- `` `p `` means that the result of `p` is dropped,
- `\p` means that the result of `p` is taken,
- `p ^ q` means that results of `p` and `q` are taken as a product, and
- `p @a` means that the results of `p` are passed to the function `a` and that result is returned.

The difficulty is in implementing the concatenation combinator `^`. The type of the result of the concatenation depends on the types of the arguments.

Using static sums and the product type, the pick notation for monads can be implemented as follows:

```
functor MkMonadPick (include MONAD) = let
   open StaticSum
in
   struct
      fun `a = inL (a >>= (fn _ => return ()))
      val \ = inR
      fun a @ f = out a >>= (return o f)
      fun a ^ b =
          (match b o match a)
             (fn a =>
                 (fn b => inL (a >>= (fn _ => b)),
                  fn b => inR (a >>= (fn _ => b))),
              fn a =>
                 (fn b => inR (a >>= (fn a => b >>= (fn _ => return a))),
                  fn b => inR (a >>= (fn a => b >>= (fn b => return (a & b))))))
   end
end
```

The above implementation is inefficient, however. It uses many more bind operations, >>=, than necessary. That can be solved with an additional level of abstraction:

```
functor MkMonadPick (include MONAD) = let
   open StaticSum
in
   struct
      fun `a = inL (fn b => a >>= (fn _ => b ()))
      fun \a = inR (fn b => a >>= b)
      fun a @ f = out a (return o f)
      fun a ^ b =
          (match b o match a)
             (fn a => (fn b => inL (fn c => a (fn () => b c)),
                       fn b => inR (fn c => a (fn () => b c))),
              fn a => (fn b => inR (fn c => a (fn a => b (fn () => c a))),
                       fn b => inR (fn c => a (fn a => b (fn b => c (a & b))))))
   end
end
```

After instantiating and opening either of the above monad pick implementations, the previously given definition of `p` can be compiled and results in a parser whose result is of type `int`. Here is a functor to test the theory:

```
functor Test (Arg : PARSING) = struct
   local
      structure Pick = MkMonadPick (Arg)
      open Pick Arg
   in
      val p : int t =
          `lparen ^ \int ^ `comma ^ \int ^ `rparen @ (fn x & y => x + y)
   end
end
```

Also see

There are a number of related techniques. Here are some of them.

- Fold
- TypeIndexedValues

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StyleGuide

These conventions are chosen so that inertia is towards modularity, code reuse and finding bugs early, *not* to save typing.

- SyntacticConventions

Subversion

Subversion is a version control system. The MLton project used Subversion to maintain its source code, but switched to Git on 20130308.

Here are some online Subversion resources.

- Version Control with Subversion

SuccessorML

The purpose of successor ML, or sML for short, is to provide a vehicle for the continued evolution of ML, using Standard ML as a starting point. The intention is for successor ML to be a living, evolving dialect of ML that is responsive to community needs and advances in language design, implementation, and semantics.

SuccessorML Features in MLton

The following SuccessorML features have been implemented in MLton. The features are disabled by default, and may be enabled utilizing the feature's corresponding ML Basis annotation which is listed directly after the feature name. In addition, the `allowSuccessorML {false|true}` annotation can be used to simultaneously enable all of the features.

- `do` Declarations: `allowDoDecls {false|true}`

  Allow a `do` *exp* declaration form, which evaluates *exp* for its side effects. The following example uses a `do` declaration:

  ```
  do print "Hello world.\n"
  ```

  and is equivalent to:

  ```
  val () = print "Hello world.\n"
  ```

- Extended Constants: `allowExtendedConsts {false|true}`

  Allow or disallow all of the extended constants features. This is a proxy for all of the following annotations.

  - Extended Numeric Constants: `allowExtendedNumConsts {false|true}`

    Allow underscores as a separator in numeric constants and allow binary integer and word constants.

    Underscores in a numeric constant must occur between digits and consecutive underscores are allowed.

    Binary integer constants use the prefix `0b` and binary word constants use the prefix `0wb`.

    The following example uses extended numeric constants (although it may be incorrectly syntax highlighted):

    ```
    val pb = 0b10101
    val nb = ~0b10_10_10
    val wb = 0wb1010
    val i = 4__327__829
    val r = 6.022_140_9e23
    ```

  - Extended Text Constants: `allowExtendedTextConsts {false|true}`

    Allow characters with integer codes $\geq$ 128 and $\leq$ 247 that correspond to syntactically well-formed UTF-8 byte sequences in text constants.

    Any 1, 2, 3, or 4 byte sequence that can be properly decoded to a binary number according to the UTF-8 encoding/decoding scheme is allowed in a text constant (but invalid sequences are not explicitly rejected) and denotes the corresponding sequence of characters with integer codes $\geq$ 128 and $\leq$ 247. This feature enables "UTF-8 convenience" (but not comprehensive Unicode support); in particular, it allows one to copy text from a browser and paste it into a string constant in an editor and, furthermore, if the string is printed to a terminal, then will (typically) appear as the original text. The following example uses UTF-8 byte sequences:

    ```
    val s1 : String.string = "\240\159\130\161"
    val s2 : String.string = "&#x1f0a1;"
    val _ = print ("s1 --> " ^ s1 ^ "\n")
    val _ = print ("s2 --> " ^ s2 ^ "\n")
    val _ = print ("String.size s1 --> " ^ Int.toString (String.size s1) ^ "\n")
    val _ = print ("String.size s2 --> " ^ Int.toString (String.size s2) ^ "\n")
    val _ = print ("s1 = s2 --> " ^ Bool.toString (s1 = s2) ^ "\n")
    ```

    and, when compiled and executed, will display:

```
s1 --> &#x1f0a1;
s2 --> &#x1f0a1;
String.size s1 --> 4
String.size s2 --> 4
s1 = s2 --> true
```

Note that the `String.string` type corresponds to any sequence of 8-bit values, including invalid UTF-8 sequences; hence the string constant `"\192"` (a UTF-8 leading byte with no UTF-8 continuation byte) is valid. Similarly, the `Char.char` type corresponds to a single 8-bit value; hence the char constant `#"α"` is not valid, as the text constant `"α"` denotes a sequence of two 8-bit values.

- Line Comments: `allowLineComments {false|true}`

  Allow line comments beginning with the token `(*)`. The following example uses a line comment:

  ```
  (*) This is a line comment
  ```

  Line comments properly nest within block comments. The following example uses line comments nested within block comments:

  ```
  (*
  val x = 4 (*) This is a line comment
  *)

  (*
  val y = 5 (*) This is a line comment *)
  *)
  ```

- Optional Pattern Bars: `allowOptBar {false|true}`

  Allow a bar to appear before the first match rule of a `case`, `fn`, or `handle` expression, allow a bar to appear before the first function-value binding of a `fun` declaration, and allow a bar to appear before the first constructor binding or description of a `datatype` declaration or specification. The following example uses leading bars in a `datatype` declaration, a `fun` declaration, and a `case` expression:

  ```
  datatype t =
    | C
    | B
    | A

  fun
    | f NONE = 0
    | f (SOME t) =
       (case t of
          | A => 1
          | B => 2
          | C => 3)
  ```

  By eliminating the special case of the first element, this feature allows for simpler refactoring (e.g., sorting the lines of the `datatype` declaration's constructor bindings to put the constructors in alphabetical order).

- Optional Semicolons: `allowOptSemicolon {false|true}`

  Allow a semicolon to appear after the last expression in a sequence or `let`-body expression. The following example uses a trailing semicolon in the body of a `let` expression:

  ```
  fun h z =
    let
      val x = 3 * z
    in
       f x ;
       g x ;
    end
  ```

By eliminating the special case of the last element, this feature allows for simpler refactoring.

- Disjunctive (Or) Patterns: `allowOrPats {false|true}`

  Allow disjunctive (a.k.a., "or") patterns of the form *pat*$_1$ `|` *pat*$_2$, which matches a value that matches either *pat*$_1$ or *pat*$_2$. Disjunctive patterns have lower precedence than `as` patterns and constraint patterns, much as `orelse` expressions have lower precedence than `andalso` expressions and constraint expressions. Both sub-patterns of a disjunctive pattern must bind the same variables with the same types. The following example uses disjunctive patterns:

```
datatype t = A of int | B of int | C of int | D of int * int | E of int * int

fun f t =
  case t of
     A x | B x | C x => x + 1
   | D (x, _) | E (_, x) => x * 2
```

- Record Punning Expressions: `allowRecordPunExps {false|true}`

  Allow record punning expressions, whereby an identifier *vid* as an expression row in a record expression denotes the expression row *vid* =*vid* (i.e., treating a label as a variable). The following example uses record punning expressions (and also record punning patterns):

```
fun incB r =
  case r of {a, b, c} => {a, b = b + 1, c}
```

  and is equivalent to:

```
fun incB r =
  case r of {a = a, b = b, c = c} => {a = a, b = b + 1, c = c}
```

- `withtype` in Signatures: `allowSigWithtype {false|true}`

  Allow `withtype` to modify a `datatype` specification in a signature. The following example uses `withtype` in a signature (and also `withtype` in a declaration):

```
signature STREAM =
  sig
    datatype 'a u = Nil | Cons of 'a * 'a t
    withtype 'a t = unit -> 'a u
  end
structure Stream : STREAM =
  struct
    datatype 'a u = Nil | Cons of 'a * 'a t
    withtype 'a t = unit -> 'a u
  end
```

  and is equivalent to:

```
signature STREAM =
  sig
    datatype 'a u = Nil | Cons of 'a * (unit -> 'a u)
    type 'a t = unit -> 'a u
  end
structure Stream : STREAM =
  struct
    datatype 'a u = Nil | Cons of 'a * (unit -> 'a u)
    type 'a t = unit -> 'a u
  end
```

- Vector Expressions and Patterns: `allowVectorExpsAndPats {false|true}`

  Allow or disallow vector expressions and vector patterns. This is a proxy for all of the following annotations.

- Vector Expressions: `allowVectorExps {false|true}`
  Allow vector expressions of the form `#[`exp_0`, `exp_1`, ..., `exp_{n-1}`]` (where $n \geq 0$). The expression has type τ `vector` when each expression exp_i has type τ.
- Vector Patterns: `allowVectorPats {false|true}`
  Allow vector patterns of the form `#[`pat_0`, `pat_1`, ..., `pat_{n-1}`]` (where $n \geq 0$). The pattern matches values of type τ `vector` when each pattern pat_i matches values of type τ.

SureshJagannathan

I am an Associate Professor at the Department of Computer Science at Purdue University. My research focus is in programming language design and implementation, concurrency, and distributed systems. I am interested in various aspects of MLton, mostly related to (in no particular order): (1) control-flow analysis (2) representation strategies (e.g., flattening), (3) IR formats, and (4) extensions for distributed programming.

Please see my Home page for more details.

Swerve

Swerve is an HTTP server written in SML, originally developed with SML/NJ. RayRacine ported Swerve to MLton in January 2005.

Download the port.

Excerpt from the included `README`:

> Total testing of this port consisted of a successful compile, startup, and serving one html page with one gif image. Given that the original code was throughly designed and implemented in a thoughtful manner and I expect it is quite usable modulo a few minor bugs introduced by my porting effort.

Swerve is described in Shipman02.

SXML

SXML is an IntermediateLanguage, translated from XML by Monomorphise, optimized by SXMLSimplify, and translated by ClosureConvert to SSA.

Description

SXML is a simply-typed version of XML.

Implementation

- `sxml.sig`
- `sxml.fun`
- `sxml-tree.sig`

Type Checking

SXML shares the type checker for XML.

Details and Notes

There are only two differences between XML and SXML. First, SXML `val`, `fun`, and `datatype` declarations always have an empty list of type variables. Second, SXML variable references always have an empty list of type arguments. Constructors uses can only have a nonempty list of type arguments if the constructor is a primitive.

Although we could rely on the type system to enforce these constraints by parameterizing the XML signature, StephenWeeks did so in a previous version of the compiler, and the software engineering gains were not worth the effort.

SXMLShrink

SXMLShrink is an optimization pass for the SXML IntermediateLanguage, invoked from SXMLSimplify.

Description

This pass performs optimizations based on a reduction system.

Implementation

- `shrink.sig`
- `shrink.fun`

Details and Notes

SXML shares the XMLShrink simplifier.

SXMLSimplify

The optimization passes for the SXML IntermediateLanguage are collected and controlled by the `SxmlSimplify` functor (`sxml-simplify.sig`, `sxml-simplify.fun`).

The following optimization passes are implemented:

- Polyvariance
- SXMLShrink

The following implementation passes are implemented:

- ImplementExceptions
- ImplementSuffix

The following optimization passes are not implemented, but might prove useful:

- Uncurry
- LambdaLift

The optimization passes can be controlled from the command-line by the options

- `-diag-pass <pass>` — keep diagnostic info for pass
- `-disable-pass <pass>` — skip optimization pass (if normally performed)
- `-enable-pass <pass>` — perform optimization pass (if normally skipped)
- `-keep-pass <pass>` — keep the results of pass
- `-sxml-passes <passes>` — sxml optimization passes

SyntacticConventions

Here are a number of syntactic conventions useful for programming in SML.

General

- A line of code never exceeds 80 columns.
- Only split a syntactic entity across multiple lines if it doesn't fit on one line within 80 columns.
- Use alphabetical order wherever possible.
- Avoid redundant parentheses.
- When using `:`, there is no space before the colon, and a single space after it.

Identifiers

- Variables, record labels and type constructors begin with and use small letters, using capital letters to separate words.

```
cost
maxValue
```

- Variables that represent collections of objects (lists, arrays, vectors, ...) are often suffixed with an `s`.

```
xs
employees
```

- Constructors, structure identifiers, and functor identifiers begin with a capital letter.

```
Queue
LinkedList
```

- Signature identifiers are in all capitals, using _ to separate words.

```
LIST
BINARY_HEAP
```

Types

- Alphabetize record labels. In a record type, there are spaces after colons and commas, but not before colons or commas, or at the delimiters `{` and `}`.

```
{bar: int, foo: int}
```

- Only split a record type across multiple lines if it doesn't fit on one line. If a record type must be split over multiple lines, put one field per line.

```
{bar: int,
 foo: real * real,
 zoo: bool}
```

- In a tuple type, there are spaces before and after each `*`.

```
int * bool * real
```

- Only split a tuple type across multiple lines if it doesn't fit on one line. In a tuple type split over multiple lines, there is one type per line, and the `*`-s go at the beginning of the lines.

  ```
  int
  * bool
  * real
  ```

  It may also be useful to parenthesize to make the grouping more apparent.

  ```
  (int
   * bool
   * real)
  ```

- In an arrow type split over multiple lines, put the arrow at the beginning of its line.

  ```
  int * real
  -> bool
  ```

  It may also be useful to parenthesize to make the grouping more apparent.

  ```
  (int * real
   -> bool)
  ```

- Avoid redundant parentheses.
- Arrow types associate to the right, so write

  ```
  a -> b -> c
  ```

  not

  ```
  a -> (b -> c)
  ```

- Type constructor application associates to the left, so write

  ```
  int ref list
  ```

  not

  ```
  (int ref) list
  ```

- Type constructor application binds more tightly than a tuple type, so write

  ```
  int list * bool list
  ```

  not

  ```
  (int list) * (bool list)
  ```

- Tuple types bind more tightly than arrow types, so write

  ```
  int * bool -> real
  ```

  not

  ```
  (int * bool) -> real
  ```

Core

- A core expression or declaration split over multiple lines does not contain any blank lines.
- A record field selector has no space between the `#` and the record label. So, write

  ```
  #foo
  ```

  not

  ```
  # foo
  ```

- A tuple has a space after each comma, but not before, and not at the delimiters `(` and `)`.

  ```
  (e1, e2, e3)
  ```

- A tuple split over multiple lines has one element per line, and the commas go at the end of the lines.

  ```
  (e1,
   e2,
   e3)
  ```

- A list has a space after each comma, but not before, and not at the delimiters `[` and `]`.

  ```
  [e1, e2, e3]
  ```

- A list split over multiple lines has one element per line, and the commas at the end of the lines.

  ```
  [e1,
   e2,
   e3]
  ```

- A record has spaces before and after =, a space after each comma, but not before, and not at the delimiters `{` and `}`. Field names appear in alphabetical order.

  ```
  {bar = 13, foo = true}
  ```

- A sequence expression has a space after each semicolon, but not before.

  ```
  (e1; e2; e3)
  ```

- A sequence expression split over multiple lines has one expression per line, and the semicolons at the beginning of lines. Lisp and Scheme programmers may find this hard to read at first.

  ```
  (e1
   ; e2
   ; e3)
  ```

  Rationale: this makes it easy to visually spot the beginning of each expression, which becomes more valuable as the expressions themselves are split across multiple lines.

- An application expression has a space between the function and the argument. There are no parens unless the argument is a tuple (in which case the parens are really part of the tuple, not the application).

  ```
  f a
  f (a1, a2, a3)
  ```

- Avoid redundant parentheses. Application associates to left, so write

  ```
  f a1 a2 a3
  ```

not

```
((f a1) a2) a3
```

- Infix operators have a space before and after the operator.

```
x + y
x * y - z
```

- Avoid redundant parentheses. Use OperatorPrecedence. So, write

```
x + y * z
```

not

```
x + (y * z)
```

- An `andalso` expression split over multiple lines has the `andalso` at the beginning of subsequent lines.

```
e1
andalso e2
andalso e3
```

- A `case` expression is indented as follows

```
case e1 of
   p1 => e1
 | p2 => e2
 | p3 => e3
```

- A `datatype`'s constructors are alphabetized.

```
datatype t = A | B | C
```

- A `datatype` declaration has a space before and after each `|`.

```
datatype t = A | B of int | C
```

- A `datatype` split over multiple lines has one constructor per line, with the `|` at the beginning of lines and the constructors beginning 3 columns to the right of the `datatype`.

```
datatype t =
   A
 | B
 | C
```

- A `fun` declaration may start its body on the subsequent line, indented 3 spaces.

```
fun f x y =
   let
      val z = x + y + z
   in
      z
   end
```

- An `if` expression is indented as follows.

```
if e1
   then e2
else e3
```

- A sequence of `if`-`then`-`else`-s is indented as follows.

```
if e1
   then e2
else if e3
   then e4
else if e5
   then e6
else e7
```

- A `let` expression has the `let`, `in`, and `end` on their own lines, starting in the same column. Declarations and the body are indented 3 spaces.

```
let
   val x = 13
   val y = 14
in
   x + y
end
```

- A `local` declaration has the `local`, `in`, and `end` on their own lines, starting in the same column. Declarations are indented 3 spaces.

```
local
   val x = 13
in
   val y = x
end
```

- An `orelse` expression split over multiple lines has the `orelse` at the beginning of subsequent lines.

```
e1
orelse e2
orelse e3
```

- A `val` declaration has a space before and after the `=`.

```
val p = e
```

- A `val` declaration can start the expression on the subsequent line, indented 3 spaces.

```
val p =
   if e1 then e2 else e3
```

Signatures

- A `signature` declaration is indented as follows.

```
signature FOO =
   sig
      val x: int
   end
```

Exception: a signature declaration in a file to itself can omit the indentation to save horizontal space.

```
signature FOO =
sig

val x: int

end
```

In this case, there should be a blank line after the `sig` and before the `end`.

- A `val` specification has a space after the colon, but not before.

```
val x: int
```

Exception: in the case of operators (like +), there is a space before the colon to avoid lexing the colon as part of the operator.

```
val + : t * t -> t
```

- Alphabetize specifications in signatures.

```
sig
   val x: int
   val y: bool
end
```

Structures

- A `structure` declaration has a space on both sides of the =.

```
structure Foo = Bar
```

- A `structure` declaration split over multiple lines is indented as follows.

```
structure S =
   struct
      val x = 13
   end
```

Exception: a structure declaration in a file to itself can omit the indentation to save horizontal space.

```
structure S =
struct

val x = 13

end
```

In this case, there should be a blank line after the `struct` and before the `end`.

- Declarations in a `struct` are separated by blank lines.

```
struct
   val x =
      let
         y = 13
      in
         y + 1
      end

   val z = 14
end
```

Functors

- A `functor` declaration has spaces after each `:` (or `:>`) but not before, and a space before and after the `=`. It is indented as follows.

```
functor Foo (S: FOO_ARG): FOO =
   struct
      val x = S.x
   end
```

Exception: a functor declaration in a file to itself can omit the indentation to save horizontal space.

```
functor Foo (S: FOO_ARG): FOO =
struct

val x = S.x

end
```

In this case, there should be a blank line after the `struct` and before the `end`.

Talk

The MLton Standard ML Compiler

Henry Cejtin, Matthew Fluet, Suresh Jagannathan, Stephen Weeks

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Dive In

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Folk Lore

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TalkMLtonApproach

MLton's Approach

- whole-program optimization using a simply-typed, first-order intermediate language
- ensures programs are not penalized for exploiting abstraction and modularity

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TalkMLtonFeatures

MLton Features

- Supports full Standard ML language and Basis Library
- Generates standalone executables
- Extensions
  - Foreign function interface (SML to C, C to SML)
  - ML Basis system for programming in the very large
  - Extension libraries

See Features.

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TalkMLtonHistory

MLton History

April 1997	Stephen Weeks wrote a defunctorizer for SML/NJ
Aug. 1997	Begin independent compiler (`smlc`)
Oct. 1997	Monomorphiser
Nov. 1997	Polyvariant higher-order control-flow analysis (10,000 lines)
March 1999	First release of MLton (48,006 lines)
Jan. 2002	MLton at 102,541 lines
Jan. 2003	MLton at 112,204 lines
Jan. 2004	MLton at 122,299 lines
Nov. 2004	MLton at 141,311 lines

See History.

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TalkStandardML

Standard ML

- a high-level language makes
  - a programmer's life easier
  - a compiler writer's life harder
- perceived overheads of features discourage their use
  - higher-order functions
  - polymorphic datatypes
  - separate modules

Also see Standard ML.

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TalkTemplate

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TalkWholeProgram

Whole Program Compiler

- Each of these techniques requires whole-program analysis
- But, additional benefits:
  - eliminate (some) variability in programming styles
  - specialize representations
  - simplifies and improves runtime system

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TILT

TILT is a Standard ML implementation.

TipsForWritingConciseSML

SML is a rich enough language that there are often several ways to express things. This page contains miscellaneous tips (ideas not rules) for writing concise SML. The metric that we are interested in here is the number of tokens or words (rather than the number of lines, for example).

Datatypes in Signatures

A seemingly frequent source of repetition in SML is that of datatype definitions in signatures and structures. Actually, it isn't repetition at all. A datatype specification in a signature, such as,

```
signature EXP = sig
   datatype exp = Fn of id * exp | App of exp * exp | Var of id
end
```

is just a specification of a datatype that may be matched by multiple (albeit identical) datatype declarations. For example, in

```
structure AnExp : EXP = struct
   datatype exp = Fn of id * exp | App of exp * exp | Var of id
end

structure AnotherExp : EXP = struct
   datatype exp = Fn of id * exp | App of exp * exp | Var of id
end
```

the types `AnExp.exp` and `AnotherExp.exp` are two distinct types. If such generativity isn't desired or needed, you can avoid the repetition:

```
structure Exp = struct
   datatype exp = Fn of id * exp | App of exp * exp | Var of id
end

signature EXP = sig
   datatype exp = datatype Exp.exp
end

structure Exp : EXP = struct
   open Exp
end
```

Keep in mind that this isn't semantically equivalent to the original.

Clausal Function Definitions

The syntax of clausal function definitions is rather repetitive. For example,

```
fun isSome NONE = false
  | isSome (SOME _) = true
```

is more verbose than

```
val isSome =
 fn NONE => false
  | SOME _ => true
```

For recursive functions the break-even point is one clause higher. For example,

```
fun fib 0 = 0
  | fib 1 = 1
  | fib n = fib (n-1) + fib (n-2)
```

isn't less verbose than

```
val rec fib =
 fn 0 => 0
  | 1 => 1
  | n => fib (n-1) + fib (n-2)
```

It is quite often the case that a curried function primarily examines just one of its arguments. Such functions can be written particularly concisely by making the examined argument last. For example, instead of

```
fun eval (Fn (v, b)) env => ...
  | eval (App (f, a) env => ...
  | eval (Var v) env => ...
```

consider writing

```
fun eval env =
 fn Fn (v, b) => ...
  | App (f, a) => ...
  | Var v => ...
```

Parentheses

It is a good idea to avoid using lots of irritating superfluous parentheses. An important rule to know is that prefix function application in SML has higher precedence than any infix operator. For example, the outer parentheses in

```
(square (5 + 1)) + (square (5 * 2))
```

are superfluous.

People trained in other languages often use superfluous parentheses in a number of places. In particular, the parentheses in the following examples are practically always superfluous and are best avoided:

```
if (condition) then ... else ...
while (condition) do ...
```

The same basically applies to case expressions:

```
case (expression) of ...
```

It is not uncommon to match a tuple of two or more values:

```
case (a, b) of
   (A1, B1) => ...
 | (A2, B2) => ...
```

Such case expressions can be written more concisely with an infix product constructor:

```
case a & b of
   A1 & B1 => ...
 | A2 & B2 => ...
```

Conditionals

Repeated sequences of conditionals such as

```
if x < y then ...
else if x = y then ...
else ...
```

can often be written more concisely as case expressions such as

```
case Int.compare (x, y) of
   LESS => ...
 | EQUAL => ...
 | GREATER => ...
```

For a custom comparison, you would then define an appropriate datatype and a reification function. An alternative to using datatypes is to use dispatch functions

```
comparing (x, y)
{lt = fn () => ...,
 eq = fn () => ...,
 gt = fn () => ...}
```

where

```
fun comparing (x, y) {lt, eq, gt} =
    (case Int.compare (x, y) of
        LESS => lt
      | EQUAL => eq
      | GREATER => gt) ()
```

An advantage is that no datatype definition is needed. A disadvantage is that you can't combine multiple dispatch results easily.

Command-Query Fusion

Many are familiar with the Command-Query Separation Principle. Adhering to the principle, a signature for an imperative stack might contain specifications

```
val isEmpty : 'a t -> bool
val pop : 'a t -> 'a
```

and use of a stack would look like

```
if isEmpty stack
then ... pop stack ...
else ...
```

or, when the element needs to be named,

```
if isEmpty stack
then let val elem = pop stack in ... end
else ...
```

For efficiency, correctness, and conciseness, it is often better to combine the query and command and return the result as an option:

```
val pop : 'a t -> 'a option
```

A use of a stack would then look like this:

```
case pop stack of
   NONE => ...
 | SOME elem => ...
```

ToMachine

ToMachine is a translation pass from the RSSA IntermediateLanguage to the Machine IntermediateLanguage.

Description

This pass converts from a RSSA program into a Machine program.

It uses AllocateRegisters, Chunkify, and ParallelMove.

Implementation

- `backend.sig`
- `backend.fun`

Details and Notes

Because the MLton runtime system is shared by all codegens, it is most convenient to decide on stack layout *before* any codegen takes over. In particular, we compute all the stack frame info for each RSSA function, including stack size, garbage collector masks for each frame, etc. To do so, the Machine IntermediateLanguage imagines an abstract machine with an infinite number of (pseudo-)registers of every size. A liveness analysis determines, for each variable, whether or not it is live across a point where the runtime system might take over (for example, any garbage collection point) or a non-tail call to another RSSA function. Those that are live go on the stack, while those that aren't live go into psuedo-registers. From this information, we know all we need to about each stack frame. On the downside, nothing further on is allowed to change this stack info; it is set in stone.

TomMurphy

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Home page

ToRSSA

ToRSSA is a translation pass from the SSA2 IntermediateLanguage to the RSSA IntermediateLanguage.

Description

This pass converts a SSA2 program into a RSSA program.

It uses PackedRepresentation.

Implementation

- `ssa-to-rssa.sig`
- `ssa-to-rssa.fun`

Details and Notes

ToSSA2

ToSSA2 is a translation pass from the SSA IntermediateLanguage to the SSA2 IntermediateLanguage.

Description

This pass is a simple conversion from a SSA program into a SSA2 program.

The only interesting portions of the translation are:

- an SSA `ref` type becomes an object with a single mutable field
- `array`, `vector`, and `ref` are eliminated in favor of select and updates
- `Case` transfers separate discrimination and constructor argument selects

Implementation

- `ssa-to-ssa2.sig`
- `ssa-to-ssa2.fun`

Details and Notes

TypeChecking

MLton's type checker follows the Definition closely, so you may find differences between MLton and other SML compilers that do not follow the Definition so closely. In particular, SML/NJ has many deviations from the Definition — please see SMLNJDeviations for those that we are aware of.

In some respects MLton's type checker is more powerful than other SML compilers, so there are programs that MLton accepts that are rejected by some other SML compilers. These kinds of programs fall into a few simple categories.

- MLton resolves flexible record patterns using a larger context than many other SML compilers. For example, MLton accepts the following.

```
fun f {x, ...} = x
val _ = f {x = 13, y = "foo"}
```

- MLton uses as large a context as possible to resolve the type of variables constrained by the value restriction to be monotypes. For example, MLton accepts the following.

```
structure S:
   sig
      val f: int -> int
   end =
   struct
      val f = (fn x => x) (fn y => y)
   end
```

Type error messages

To aid in the understanding of type errors, MLton's type checker displays type errors differently than other SML compilers. In particular, when two types are different, it is important for the programmer to easily understand why they are different. So, MLton displays only the differences between two types that don't match, using underscores for the parts that match. For example, if a function expects `real * int` but gets `real * real`, the type error message would look like

```
expects: _ * [int]
but got: _ * [real]
```

As another aid to spotting differences, MLton places brackets `[]` around the parts of the types that don't match. A common situation is when a function receives a different number of arguments than it expects, in which case you might see an error like

```
expects: [int * real]
but got: [int * real * string]
```

The brackets make it easy to see that the problem is that the tuples have different numbers of components — not that the components don't match. Contrast that with a case where a function receives the right number of arguments, but in the wrong order, in which case you might see an error like

```
expects: [int] * [real]
but got: [real] * [int]
```

Here the brackets make it easy to see that the components do not match.

We appreciate feedback on any type error messages that you find confusing, or suggestions you may have for improvements to error messages.

The shortest/most-recent rule for type names

In a type error message, MLton often has a number of choices in deciding what name to use for a type. For example, in the following type-incorrect program

```
type t = int
fun f (x: t) = x
val _ = f "foo"
```

MLton reports the error message

```
Error: z.sml 3.9-3.15.
  Function applied to incorrect argument.
    expects: [t]
    but got: [string]
    in: f "foo"
```

MLton could have reported `expects: [int]` instead of `expects: [t]`. However, MLton uses the shortest/most-recent rule in order to decide what type name to display. This rule means that, at the point of the error, MLton first looks for the shortest name for a type in terms of number of structure identifiers (e.g. `foobar` is shorter than `A.t`). Next, if there are multiple names of the same length, then MLton uses the most recently defined name. It is this tiebreaker that causes MLton to prefer `t` to `int` in the above example.

In signature matching, most recently defined is not taken to include all of the definitions introduced by the structure (since the matching takes place outside the structure and before it is defined). For example, in the following type-incorrect program

```
structure S:
   sig
      val x: int
   end =
   struct
      type t = int
      val x = "foo"
   end
```

MLton reports the error message

```
Error: z.sml 2.4-4.6.
  Variable in structure disagrees with signature (type): x.
    structure: val x: [string]
    defn at: z.sml 7.11-7.11
    signature: val x: [int]
    spec at: z.sml 3.11-3.11
```

If there is a type that only exists inside the structure being matched, then the prefix `_str.` is used. For example, in the following type-incorrect program

```
structure S:
   sig
      val x: int
   end =
   struct
      datatype t = T
      val x = T
   end
```

MLton reports the error message

```
Error: z.sml 2.4-4.6.
  Variable in structure disagrees with signature (type): x.
    structure: val x: [_str.t]
    defn at: z.sml 7.11-7.11
```

```
    signature: val x: [int]
    spec at: z.sml 3.11-3.11
```

in which the `[_str.t]` refers to the type defined in the structure.

TypeConstructor

In Standard ML, a type constructor is a function from types to types. Type constructors can be *nullary*, meaning that they take no arguments, as in `char`, `int`, and `real`. Type constructors can be *unary*, meaning that they take one argument, as in `array`, `list`, and `vector`. A program can define a new type constructor in two ways: a `type` definition or a `datatype` declaration. User-defined type constructors can can take any number of arguments.

```
datatype t = T of int * real            (* 0 arguments *)
type 'a t = 'a * int                    (* 1 argument *)
datatype ('a, 'b) t = A | B of 'a * 'b  (* 2 arguments *)
type ('a, 'b, 'c) t = 'a * ('b  -> 'c)  (* 3 arguments *)
```

Here are the syntax rules for type constructor application.

- Type constructor application is written in postfix. So, one writes `int list`, not `list int`.
- Unary type constructors drop the parens, so one writes `int list`, not `(int) list`.
- Nullary type constructors drop the argument entirely, so one writes `int`, not `() int`.
- N-ary type constructors use tuple notation; for example, `(int, real) t`.
- Type constructor application associates to the left. So, `int ref list` is the same as `(int ref) list`.

TypeIndexedValues

Standard ML does not support ad hoc polymorphism. This presents a challenge to programmers. The problem is that at first glance there seems to be no practical way to implement something like a function for converting a value of any type to a string or a function for computing a hash value for a value of any type. Fortunately there are ways to implement type-indexed values in SML as discussed in Yang98. Various articles such as Danvy98, Ramsey11, Elsman04, Kennedy04, and Benton05 also contain examples of type-indexed values.

NOTE: The technique used in the following example uses an early (and somewhat broken) variation of the basic technique used in an experimental generic programming library (see README) that can be found from the MLton repository. The generic programming library also includes a more advanced generic pretty printing function (see pretty.sig).

Example: Converting any SML value to (roughly) SML syntax

Consider the problem of converting any SML value to a textual presentation that matches the syntax of SML as closely as possible. One solution is a type-indexed function that maps a given type to a function that maps any value (of the type) to its textual presentation. A type-indexed function like this can be useful for a variety of purposes. For example, one could use it to show debugging information. We'll call this function "show".

We'll do a fairly complete implementation of show. We do not distinguish infix and nonfix constructors, but that is not an intrinsic property of SML datatypes. We also don't reconstruct a type name for the value, although it would be particularly useful for functional values. To reconstruct type names, some changes would be needed and the reader is encouraged to consider how to do that. A more realistic implementation would use some pretty printing combinators to compute a layout for the result. This should be a relatively easy change (given a suitable pretty printing library). Cyclic values (through references and arrays) do not have a standard textual presentation and it is impossible to convert arbitrary functional values (within SML) to a meaningful textual presentation. Finally, it would also make sense to show sharing of references and arrays. We'll leave these improvements to an actual library implementation.

The following code uses the fixpoint framework and other utilities from an Extended Basis library (see README).

Signature

Let's consider the design of the SHOW signature:

```
infixr -->

signature SHOW = sig
   type 'a t        (* complete type-index *)
   type 'a s        (* incomplete sum *)
   type ('a, 'k) p  (* incomplete product *)
   type u           (* tuple or unlabelled product *)
   type l           (* record or labelled product *)

   val show : 'a t -> 'a -> string

   (* user-defined types *)
   val inj : ('a -> 'b) -> 'b t -> 'a t

   (* tuples and records *)
   val * : ('a, 'k) p * ('b, 'k) p -> (('a, 'b) product, 'k) p

   val U :           'a t -> ('a, u) p
   val L : string -> 'a t -> ('a, l) p

   val tuple  : ('a, u) p -> 'a t
   val record : ('a, l) p -> 'a t

   (* datatypes *)
   val + : 'a s * 'b s -> (('a, 'b) sum) s
```

```
   val C0 : string -> unit s
   val C1 : string -> 'a t -> 'a s

   val data : 'a s -> 'a t

   val Y : 'a t Tie.t

   (* exceptions *)
   val exn : exn t
   val regExn : (exn -> ('a * 'a s) option) -> unit

   (* some built-in type constructors *)
   val refc : 'a t -> 'a ref t
   val array : 'a t -> 'a array t
   val list : 'a t -> 'a list t
   val vector : 'a t -> 'a vector t
   val --> : 'a t * 'b t -> ('a -> 'b) t

   (* some built-in base types *)
   val string : string t
   val unit : unit t
   val bool : bool t
   val char : char t
   val int : int t
   val word : word t
   val real : real t
end
```

While some details are shaped by the specific requirements of `show`, there are a number of (design) patterns that translate to other type-indexed values. The former kind of details are mostly shaped by the syntax of SML values that `show` is designed to produce. To this end, abstract types and phantom types are used to distinguish incomplete record, tuple, and datatype type-indices from each other and from complete type-indices. Also, names of record labels and datatype constructors need to be provided by the user.

Arbitrary user-defined datatypes

Perhaps the most important pattern is how the design supports arbitrary user-defined datatypes. A number of combinators together conspire to provide the functionality. First of all, to support new user-defined types, a combinator taking a conversion function to a previously supported type is provided:

```
val inj : ('a -> 'b) -> 'b t -> 'a t
```

An injection function is sufficient in this case, but in the general case, an embedding with injection and projection functions may be needed.

To support products (tuples and records) a product combinator is provided:

```
val * : ('a, 'k) p * ('b, 'k) p -> (('a, 'b) product, 'k) p
```

The second (phantom) type variable `'k` is there to distinguish between labelled and unlabelled products and the type `p` distinguishes incomplete products from complete type-indices of type `t`. Most type-indexed values do not need to make such distinctions.

To support sums (datatypes) a sum combinator is provided:

```
val + : 'a s * 'b s -> (('a, 'b) sum) s
```

Again, the purpose of the type `s` is to distinguish incomplete sums from complete type-indices of type `t`, which usually isn't necessary.

Finally, to support recursive datatypes, including sets of mutually recursive datatypes, a fixpoint tier is provided:

```
val Y : 'a t Tie.t
```

Together these combinators (with the more domain specific combinators U, L, tuple, record, C0, C1, and data) enable one to encode a type-index for any user-defined datatype.

Exceptions

The exn type in SML is a universal type into which all types can be embedded. SML also allows a program to generate new exception variants at run-time. Thus a mechanism is required to register handlers for particular variants:

```
val exn : exn t
val regExn : (exn -> ('a * 'a s) option) -> unit
```

The universal exn type-index then makes use of the registered handlers. The above particular form of handler, which converts an exception value to a value of some type and a type-index for that type (essentially an existential type) is designed to make it convenient to write handlers. To write a handler, one can conveniently reuse existing type-indices:

```
exception Int of int

local
   open Show
in
   val () = regExn (fn Int v => SOME (v, C1"Int" int)
                     | _     => NONE)
end
```

Note that a single handler may actually handle an arbitrary number of different exceptions.

Other types

Some built-in and standard types typically require special treatment due to their special nature. The most important of these are arrays and references, because cyclic data (ignoring closures) and observable sharing can only be constructed through them.

When arrow types are really supported, unlike in this case, they usually need special treatment due to the contravariance of arguments.

Lists and vectors require special treatment in the case of show, because of their special syntax. This isn't usually the case.

The set of base types to support also needs to be considered unless one exports an interface for constructing type-indices for entirely new base types.

Usage

Before going to the implementation, let's look at some examples. For the following examples, we'll assume a structure binding Show :> SHOW. If you want to try the examples immediately, just skip forward to the implementation.

To use show, one first needs a type-index, which is then given to show. To show a list of integers, one would use the type-index list int, which has the type int list Show.t:

```
val "[3, 1, 4]" =
    let open Show in show (list int) end
       [3, 1, 4]
```

Likewise, to show a list of lists of characters, one would use the type-index list (list char), which has the type char list list Show.t:

```
val "[[#\"a\", #\"b\", #\"c\"], []]" =
    let open Show in show (list (list char)) end
       [[#"a", #"b", #"c"], []]
```

Handling standard types is not particularly interesting. It is more interesting to see how user-defined types can be handled. Although the `option` datatype is a standard type, it requires no special support, so we can treat it as a user-defined type. Options can be encoded easily using a sum:

```
fun option t = let
   open Show
in
   inj (fn NONE => INL ()
         | SOME v => INR v)
       (data (C0"NONE" + C1"SOME" t))
end

val "SOME 5" =
    let open Show in show (option int) end
       (SOME 5)
```

Readers new to type-indexed values might want to type annotate each subexpression of the above example as an exercise. (Use a compiler to check your annotations.)

Using a product, user specified records can be also be encoded easily:

```
val abc = let
   open Show
in
   inj (fn {a, b, c} => a & b & c)
       (record (L"a" (option int) *
                L"b" real *
                L"c" bool))
end

val "{a = SOME 1, b = 3.0, c = false}" =
    let open Show in show abc end
       {a = SOME 1, b = 3.0, c = false}
```

As you can see, both of the above use `inj` to inject user-defined types to the general purpose sum and product types.

Of particular interest is whether recursive datatypes and cyclic data can be handled. For example, how does one write a type-index for a recursive datatype such as a cyclic graph?

```
datatype 'a graph = VTX of 'a * 'a graph list ref
fun arcs (VTX (_, r)) = r
```

Using the `Show` combinators, we could first write a new type-index combinator for `graph`:

```
fun graph a = let
   open Tie Show
in
   fix Y (fn graph_a =>
             inj (fn VTX (x, y) => x & y)
                 (data (C1"VTX"
                          (tuple (U a *
                                  U (refc (list graph_a)))))))
end
```

To show a graph with integer labels

```
val a_graph = let
   val a = VTX (1, ref [])
   val b = VTX (2, ref [])
   val c = VTX (3, ref [])
   val d = VTX (4, ref [])
   val e = VTX (5, ref [])
   val f = VTX (6, ref [])
```

```
in
   arcs a := [b, d]
 ; arcs b := [c, e]
 ; arcs c := [a, f]
 ; arcs d := [f]
 ; arcs e := [d]
 ; arcs f := [e]
 ; a
end
```

we could then simply write

```
val "VTX (1, ref [VTX (2, ref [VTX (3, ref [VTX (1, %0), \
    \VTX (6, ref [VTX (5, ref [VTX (4, ref [VTX (6, %3)])])] as %3)]), \
    \VTX (5, ref [VTX (4, ref [VTX (6, ref [VTX (5, %2)])])] as %2)]), \
    \VTX (4, ref [VTX (6, ref [VTX (5, ref [VTX (4, %1)])])] as %1)] as %0)" =
    let open Show in show (graph int) end
       a_graph
```

There is a subtle gotcha with cyclic data. Consider the following code:

```
exception ExnArray of exn array

val () = let
   open Show
in
   regExn (fn ExnArray a =>
              SOME (a, C1"ExnArray" (array exn))
            | _ => NONE)
end

val a_cycle = let
   val a = Array.fromList [Empty]
in
   Array.update (a, 0, ExnArray a) ; a
end
```

Although the above looks innocent enough, the evaluation of

```
val "[|ExnArray %0|] as %0" =
    let open Show in show (array exn) end
       a_cycle
```

goes into an infinite loop. To avoid this problem, the type-index `array exn` must be evaluated only once, as in the following:

```
val array_exn = let open Show in array exn end

exception ExnArray of exn array

val () = let
   open Show
in
   regExn (fn ExnArray a =>
              SOME (a, C1"ExnArray" array_exn)
            | _ => NONE)
end

val a_cycle = let
   val a = Array.fromList [Empty]
in
   Array.update (a, 0, ExnArray a) ; a
end
```

```
val "[|ExnArray %0|] as %0" =
    let open Show in show array_exn end
       a_cycle
```

Cyclic data (excluding closures) in Standard ML can only be constructed imperatively through arrays and references (combined with exceptions or recursive datatypes). Before recursing to a reference or an array, one needs to check whether that reference or array has already been seen before. When `ref` or `array` is called with a type-index, a new cyclicity checker is instantiated.

Implementation

```
structure SmlSyntax = struct
   local
      structure CV = CharVector and C = Char
   in
      val isSym = Char.contains "!%&$#+-/:<=>?@\\~`^|*"

      fun isSymId s = 0 < size s andalso CV.all isSym s

      fun isAlphaNumId s =
          0 < size s
          andalso C.isAlpha (CV.sub (s, 0))
          andalso CV.all (fn c => C.isAlphaNum c
                                  orelse #"'" = c
                                  orelse #"_" = c) s

      fun isNumLabel s =
          0 < size s
          andalso #"0" <> CV.sub (s, 0)
          andalso CV.all C.isDigit s

      fun isId s = isAlphaNumId s orelse isSymId s

      fun isLongId s = List.all isId (String.fields (#"." <\ op =) s)

      fun isLabel s = isId s orelse isNumLabel s
   end
end

structure Show :> SHOW = struct
   datatype 'a t = IN of exn list * 'a -> bool * string
   type 'a s = 'a t
   type ('a, 'k) p = 'a t
   type u = unit
   type l = unit

   fun show (IN t) x = #2 (t ([], x))

   (* user-defined types *)
   fun inj inj (IN b) = IN (b o Pair.map (id, inj))

   local
      fun surround pre suf (_, s) = (false, concat [pre, s, suf])
      fun parenthesize x = if #1 x then surround "(" ")" x else x
      fun construct tag =
          (fn (_, s) => (true, concat [tag, " ", s])) o parenthesize
      fun check p m s = if p s then () else raise Fail (m^s)
   in
      (* tuples and records *)
      fun (IN l) * (IN r) =
```

```
    IN (fn (rs, a & b) =>
           (false, concat [#2 (l (rs, a)),
                           ", ",
                           #2 (r (rs, b))]))

val U = id
fun L l = (check SmlSyntax.isLabel "Invalid label: " l
         ; fn IN t => IN (surround (l^" = ") "" o t))

fun tuple (IN t) = IN (surround "(" ")" o t)
fun record (IN t) = IN (surround "{" "}" o t)

(* datatypes *)
fun (IN l) + (IN r) = IN (fn (rs, INL a) => l (rs, a)
                           | (rs, INR b) => r (rs, b))

fun C0 c = (check SmlSyntax.isId "Invalid constructor: " c
          ; IN (const (false, c)))
fun C1 c (IN t) = (check SmlSyntax.isId "Invalid constructor: " c
                 ; IN (construct c o t))

val data = id

fun Y ? = Tie.iso Tie.function (fn IN x => x, IN) ?

(* exceptions *)
local
   val handlers = ref ([] : (exn -> unit t option) list)
in
   val exn = IN (fn (rs, e) => let
                    fun lp [] =
                        C0(concat ["<exn:",
                                   General.exnName e,
                                   ">"])
                      | lp (f::fs) =
                        case f e
                         of NONE => lp fs
                          | SOME t => t
                    val IN f = lp (!handlers)
                 in
                    f (rs, ())
                 end)
   fun regExn f =
       handlers := (Option.map
                    (fn (x, IN f) =>
                        IN (fn (rs, ()) =>
                               f (rs, x))) o f)
                   :: !handlers
end

(* some built-in type constructors *)
local
   fun cyclic (IN t) = let
      exception E of ''a * bool ref
   in
      IN (fn (rs, v : ''a) => let
                val idx = Int.toString o length
                fun lp (E (v', c)::rs) =
                    if v' <> v then lp rs
                    else (c := false ; (false, "%"^idx rs))
                  | lp (_::rs) = lp rs
                  | lp [] = let
```

```
                                val c = ref true
                                val r = t (E (v, c)::rs, v)
                             in
                                if !c then r
                                else surround "" (" as %"^idx rs) r
                             end
                      in
                         lp rs
                      end)
         end

         fun aggregate pre suf toList (IN t) =
             IN (surround pre suf o
                 (fn (rs, a) =>
                     (false,
                      String.concatWith
                         ", "
                         (map (#2 o curry t rs)
                              (toList a)))))
      in
         fun refc ? = (cyclic o inj ! o C1"ref") ?
         fun array ? = (cyclic o aggregate "[|" "|]" (Array.foldr op:: [])) ?
         fun list ? = aggregate "[" "]" id ?
         fun vector ? = aggregate "#[" "]" (Vector.foldr op:: []) ?
      end

      fun (IN _) --> (IN _) = IN (const (false, "<fn>"))

      (* some built-in base types *)
      local
         fun mk toS = (fn x => (false, x)) o toS o (fn (_, x) => x)
      in
         val string =
             IN (surround "\"" "\"" o mk (String.translate Char.toString))
         val unit = IN (mk (fn () => "()"))
         val bool = IN (mk Bool.toString)
         val char = IN (surround "#\"" "\"" o mk Char.toString)
         val int = IN (mk Int.toString)
         val word = IN (surround "0wx" "" o mk Word.toString)
         val real = IN (mk Real.toString)
      end
   end
end

(* Handlers for standard top-level exceptions *)
val () = let
   open Show
   fun E0 name = SOME ((), C0 name)
in
   regExn (fn Bind => E0"Bind"
            | Chr => E0"Chr"
            | Div => E0"Div"
            | Domain => E0"Domain"
            | Empty => E0"Empty"
            | Match => E0"Match"
            | Option => E0"Option"
            | Overflow  => E0"Overflow"
            | Size => E0"Size"
            | Span => E0"Span"
            | Subscript => E0"Subscript"
            | _ => NONE)
 ; regExn (fn Fail s => SOME (s, C1"Fail" string)
```

```
              | _ => NONE)
end
```

Also see

There are a number of related techniques. Here are some of them.

- Fold
- StaticSum

TypeVariableScope

In Standard ML, every type variable is *scoped* (or bound) at a particular point in the program. A type variable can be either implicitly scoped or explicitly scoped. For example, `'a` is implicitly scoped in

```
val id: 'a -> 'a = fn x => x
```

and is implicitly scoped in

```
val id = fn x: 'a => x
```

On the other hand, `'a` is explicitly scoped in

```
val 'a id: 'a -> 'a = fn x => x
```

and is explicitly scoped in

```
val 'a id = fn x: 'a => x
```

A type variable can be scoped at a `val` or `fun` declaration. An SML type checker performs scope inference on each top-level declaration to determine the scope of each implicitly scoped type variable. After scope inference, every type variable is scoped at exactly one enclosing `val` or `fun` declaration. Scope inference shows that the first and second example above are equivalent to the third and fourth example, respectively.

Section 4.6 of the Definition specifies precisely the scope of an implicitly scoped type variable. A free occurrence of a type variable `'a` in a declaration `d` is said to be *unguarded* in `d` if `'a` is not part of a smaller declaration. A type variable `'a` is implicitly scoped at `d` if `'a` is unguarded in `d` and `'a` does not occur unguarded in any declaration containing `d`.

Scope inference examples

- In this example,

  ```
  val id: 'a -> 'a = fn x => x
  ```

  `'a` is unguarded in `val id` and does not occur unguarded in any containing declaration. Hence, `'a` is scoped at `val id` and the declaration is equivalent to the following.

  ```
  val 'a id: 'a -> 'a = fn x => x
  ```

- In this example,

  ```
   val f = fn x => let exception E of 'a in E x end
  ```

  `'a` is unguarded in `val f` and does not occur unguarded in any containing declaration. Hence, `'a` is scoped at `val f` and the declaration is equivalent to the following.

  ```
  val 'a f = fn x => let exception E of 'a in E x end
  ```

- In this example (taken from the Definition),

  ```
  val x: int -> int = let val id: 'a -> 'a = fn z => z in id id end
  ```

  `'a` occurs unguarded in `val id`, but not in `val x`. Hence, `'a` is implicitly scoped at `val id`, and the declaration is equivalent to the following.

  ```
  val x: int -> int = let val 'a id: 'a -> 'a = fn z => z in id id end
  ```

- In this example,

```
val f = (fn x: 'a => x) (fn y => y)
```

'a occurs unguarded in `val f` and does not occur unguarded in any containing declaration. Hence, 'a is implicitly scoped at `val f`, and the declaration is equivalent to the following.

```
val 'a f = (fn x: 'a => x) (fn y => y)
```

This does not type check due to the ValueRestriction.

- In this example,

```
fun f x =
  let
    fun g (y: 'a) = if true then x else y
  in
    g x
  end
```

'a occurs unguarded in `fun g`, not in `fun f`. Hence, 'a is implicitly scoped at `fun g`, and the declaration is equivalent to

```
fun f x =
  let
    fun 'a g (y: 'a) = if true then x else y
  in
    g x
  end
```

This fails to type check because `x` and `y` must have the same type, but the `x` occurs outside the scope of the type variable 'a. MLton reports the following error.

```
Error: z.sml 3.21-3.41.
  Then and else branches disagree.
    then: [???]
    else: ['a]
    in: if true then x else y
    note: type would escape its scope: 'a
    escape to: z.sml 1.1-6.5
```

This problem could be fixed either by adding an explicit type constraint, as in `fun f (x:'a)`, or by explicitly scoping 'a, as in `fun 'a f x =...`.

Restrictions on type variable scope

It is not allowed to scope a type variable within a declaration in which it is already in scope (see the last restriction listed on page 9 of the Definition). For example, the following program is invalid.

```
fun 'a f (x: 'a) =
   let
      fun 'a g (y: 'a) = y
   in
      ()
   end
```

MLton reports the following error.

```
Error: z.sml 3.11-3.12.
  Type variable scoped at an outer declaration: 'a.
    scoped at: z.sml 1.1-6.6
```

This is an error even if the scoping is implicit. That is, the following program is invalid as well.

```
fun f (x: 'a) =
   let
      fun 'a g (y: 'a) = y
   in
      ()
   end
```

Unicode

Support in The Definition of Standard ML

There is no real support for Unicode in the Definition; there are only a few throw-away sentences along the lines of "the characters with numbers 0 to 127 coincide with the ASCII character set."

Support in The Standard ML Basis Library

Neither is there real support for Unicode in the Basis Library. The general consensus (which includes the opinions of the editors of the Basis Library) is that the `WideChar` and `WideString` structures are insufficient for the purposes of Unicode. There is no `LargeChar` structure, which in itself is a deficiency, since a programmer can not program against the largest supported character size.

Current Support in MLton

MLton, as a minor extension over the Definition, supports UTF-8 byte sequences in text constants. This feature enables "UTF-8 convenience" (but not comprehensive Unicode support); in particular, it allows one to copy text from a browser and paste it into a string constant in an editor and, furthermore, if the string is printed to a terminal, then will (typically) appear as the original text. See the extended text constants feature of Successor ML for more details.

MLton, also as a minor extension over the Definition, supports `\Uxxxxxxxx` numeric escapes in text constants and has preliminary internal support for 16- and 32-bit characters and strings.

MLton provides `WideChar` and `WideString` structures, corresponding to 32-bit characters and strings, respectively.

Questions and Discussions

There are periodic flurries of questions and discussion about Unicode in MLton/SML. In December 2004, there was a discussion that led to some seemingly sound design decisions. The discussion started at:

- http://www.mlton.org/pipermail/mlton/2004-December/026396.html

There is a good summary of points at:

- http://www.mlton.org/pipermail/mlton/2004-December/026440.html

In November 2005, there was a followup discussion and the beginning of some coding.

- http://www.mlton.org/pipermail/mlton/2005-November/028300.html

Also see

The fxp XML parser has some support for dealing with Unicode documents.

UniversalType

A universal type is a type into which all other types can be embedded. Here's a Standard ML signature for a universal type.

```
signature UNIVERSAL_TYPE =
   sig
      type t

      val embed: unit -> ('a -> t) * (t -> 'a option)
   end
```

The idea is that `type t` is the universal type and that each call to `embed` returns a new pair of functions `(inject, project)`, where `inject` embeds a value into the universal type and `project` extracts the value from the universal type. A pair `(inject, project)` returned by `embed` works together in that `project u` will return `SOME v` if and only if `u` was created by `inject v`. If `u` was created by a different function `inject'`, then `project` returns `NONE`.

Here's an example embedding integers and reals into a universal type.

```
functor Test (U: UNIVERSAL_TYPE): sig end =
   struct
      val (intIn: int -> U.t, intOut) = U.embed ()
      val r: U.t ref = ref (intIn 13)
      val s1 =
         case intOut (!r) of
            NONE => "NONE"
          | SOME i => Int.toString i
      val (realIn: real -> U.t, realOut) = U.embed ()
      val () = r := realIn 13.0
      val s2 =
         case intOut (!r) of
            NONE => "NONE"
          | SOME i => Int.toString i
      val s3 =
         case realOut (!r) of
            NONE => "NONE"
          | SOME x => Real.toString x
      val () = print (concat [s1, " ", s2, " ", s3, "\n"])
   end
```

Applying `Test` to an appropriate implementation will print

```
13 NONE 13.0
```

Note that two different calls to embed on the same type return different embeddings.

Standard ML does not have explicit support for universal types; however, there are at least two ways to implement them.

Implementation Using Exceptions

While the intended use of SML exceptions is for exception handling, an accidental feature of their design is that the `exn` type is a universal type. The implementation relies on being able to declare exceptions locally to a function and on the fact that exceptions are generative.

```
structure U:> UNIVERSAL_TYPE =
   struct
      type t = exn

      fun 'a embed () =
         let
            exception E of 'a
```

```
            fun project (e: t): 'a option =
               case e of
                  E a => SOME a
                | _ => NONE
         in
            (E, project)
         end
   end
```

Implementation Using Functions and References

```
structure U:> UNIVERSAL_TYPE =
   struct
      datatype t = T of {clear: unit -> unit,
                         store: unit -> unit}

      fun 'a embed () =
         let
            val r: 'a option ref = ref NONE
            fun inject (a: 'a): t =
               T {clear = fn () => r := NONE,
                  store = fn () => r := SOME a}
            fun project (T {clear, store}): 'a option =
               let
                  val () = store ()
                  val res = !r
                  val () = clear ()
               in
                  res
               end
         in
            (inject, project)
         end
   end
```

Note that due to the use of a shared ref cell, the above implementation is not thread safe.

One could try to simplify the above implementation by eliminating the `clear` function, making `type t =unit -> unit`.

```
structure U:> UNIVERSAL_TYPE =
   struct
      type t = unit -> unit

      fun 'a embed () =
         let
            val r: 'a option ref = ref NONE
            fun inject (a: 'a): t = fn () => r := SOME a
            fun project (f: t): 'a option = (r := NONE; f (); !r)
         in
            (inject, project)
         end
   end
```

While correct, this approach keeps the contents of the ref cell alive longer than necessary, which could cause a space leak. The problem is in `project`, where the call to `f` stores some value in some ref cell `r'`. Perhaps `r'` is the same ref cell as `r`, but perhaps not. If we do not clear `r'` before returning from `project`, then `r'` will keep the value alive, even though it is useless.

Also see

- PropertyList: Lisp-style property lists implemented with a universal type

UnresolvedBugs

Here are the places where MLton deviates from The Definition of Standard ML (Revised) and the Basis Library. In general, MLton complies with the Definition quite closely, typically much more closely than other SML compilers (see, e.g., our list of SML/NJ's deviations). In fact, the four deviations listed here are the only known deviations, and we have no immediate plans to fix them. If you find a deviation not listed here, please report a Bug.

We don't plan to fix these bugs because the first (parsing nested cases) has historically never been accepted by any SML compiler, the second clearly indicates a problem in the Definition, and the remaining are difficult to resolve in the context of MLton's implementaton of Standard ML (and unlikely to be problematic in practice).

- MLton does not correctly parse case expressions nested within other matches. For example, the following fails.

  ```
  fun f 0 y =
        case x of
           1 => 2
         | _ => 3
    | f _ y = 4
  ```

  To do this in a program, simply parenthesize the case expression.

  Allowing such expressions, although compliant with the Definition, would be a mistake, since using parentheses is clearer and no SML compiler has ever allowed them. Furthermore, implementing this would require serious yacc grammar rewriting followed by postprocessing.

- MLton does not raise the `Bind` exception at run time when evaluating `val rec` (and `fun`) declarations that redefine identifiers that previously had constructor status. (By default, MLton does warn at compile time about `val rec` (and `fun`) declarations that redefine identifiers that previously had constructors status; see the `valrecConstr` ML Basis annotation.) For example, the Definition requires the following program to type check, but also (bizarelly) requires it to raise the `Bind` exception

  ```
  val rec NONE = fn () => ()
  ```

  The Definition's behavior is obviously an error, a mismatch between the static semantics (rule 26) and the dynamic semantics (rule 126). Given the comments on rule 26 in the Definition, it seems clear that the authors meant for `val rec` to allow an identifier's constructor status to be overridden both statically and dynamically. Hence, MLton and most SML compilers follow rule 26, but do not follow rule 126.

- MLton does not hide the equality aspect of types declared in `abstype` declarations. So, MLton accepts programs like the following, while the Definition rejects them.

  ```
  abstype t = T with end
  val _ = fn (t1, t2 : t) => t1 = t2

  abstype t = T with val a = T end
  val _ = a = a
  ```

  One consequence of this choice is that MLton accepts the following program, in accordance with the Definition.

  ```
  abstype t = T with val eq = op = end
  val _ = fn (t1, t2 : t) => eq (t1, t2)
  ```

  Other implementations will typically reject this program, because they make an early choice for the type of `eq` to be `"a * ''a -> bool` instead of `t * t -> bool`. The choice is understandable, since the Definition accepts the following program.

  ```
  abstype t = T with val eq = op = end
  val _ = eq (1, 2)
  ```

- MLton (re-)type checks each functor definition at every corresponding functor application (the compilation technique of defunctorization). One consequence of this implementation is that MLton accepts the following program, while the Definition rejects it.

```
functor F (X: sig type t end) = struct
    val f = id id
end
structure A = F (struct type t = int end)
structure B = F (struct type t = bool end)
val _ = A.f 10
val _ = B.f "dude"
```

On the other hand, other implementations will typically reject the following program, while MLton and the Definition accept it.

```
functor F (X: sig type t end) = struct
    val f = id id
end
structure A = F (struct type t = int end)
structure B = F (struct type t = bool end)
val _ = A.f 10
val _ = B.f false
```

See DreyerBlume07 for more details.

UnsafeStructure

This module is a subset of the `Unsafe` module provided by SML/NJ, with a few extract operations for `PackWord` and `PackReal`.

```
signature UNSAFE_MONO_ARRAY =
   sig
      type array
      type elem

      val create: int -> array
      val sub: array * int -> elem
      val update: array * int * elem -> unit
   end

signature UNSAFE_MONO_VECTOR =
   sig
      type elem
      type vector

      val sub: vector * int -> elem
   end

signature UNSAFE =
   sig
      structure Array:
         sig
            val create: int * 'a -> 'a array
            val sub: 'a array * int -> 'a
            val update: 'a array * int * 'a -> unit
         end
      structure CharArray: UNSAFE_MONO_ARRAY
      structure CharVector: UNSAFE_MONO_VECTOR
      structure IntArray: UNSAFE_MONO_ARRAY
      structure IntVector: UNSAFE_MONO_VECTOR
      structure Int8Array: UNSAFE_MONO_ARRAY
      structure Int8Vector: UNSAFE_MONO_VECTOR
      structure Int16Array: UNSAFE_MONO_ARRAY
      structure Int16Vector: UNSAFE_MONO_VECTOR
      structure Int32Array: UNSAFE_MONO_ARRAY
      structure Int32Vector: UNSAFE_MONO_VECTOR
      structure Int64Array: UNSAFE_MONO_ARRAY
      structure Int64Vector: UNSAFE_MONO_VECTOR
      structure IntInfArray: UNSAFE_MONO_ARRAY
      structure IntInfVector: UNSAFE_MONO_VECTOR
      structure LargeIntArray: UNSAFE_MONO_ARRAY
      structure LargeIntVector: UNSAFE_MONO_VECTOR
      structure LargeRealArray: UNSAFE_MONO_ARRAY
      structure LargeRealVector: UNSAFE_MONO_VECTOR
      structure LargeWordArray: UNSAFE_MONO_ARRAY
      structure LargeWordVector: UNSAFE_MONO_VECTOR
      structure RealArray: UNSAFE_MONO_ARRAY
      structure RealVector: UNSAFE_MONO_VECTOR
      structure Real32Array: UNSAFE_MONO_ARRAY
      structure Real32Vector: UNSAFE_MONO_VECTOR
      structure Real64Array: UNSAFE_MONO_ARRAY
      structure Vector:
         sig
            val sub: 'a vector * int -> 'a
         end
      structure Word8Array: UNSAFE_MONO_ARRAY
```

```
    structure Word8Vector: UNSAFE_MONO_VECTOR
    structure Word16Array: UNSAFE_MONO_ARRAY
    structure Word16Vector: UNSAFE_MONO_VECTOR
    structure Word32Array: UNSAFE_MONO_ARRAY
    structure Word32Vector: UNSAFE_MONO_VECTOR
    structure Word64Array: UNSAFE_MONO_ARRAY
    structure Word64Vector: UNSAFE_MONO_VECTOR

    structure PackReal32Big : PACK_REAL
    structure PackReal32Little : PACK_REAL
    structure PackReal64Big : PACK_REAL
    structure PackReal64Little : PACK_REAL
    structure PackRealBig : PACK_REAL
    structure PackRealLittle : PACK_REAL
    structure PackWord16Big : PACK_WORD
    structure PackWord16Little : PACK_WORD
    structure PackWord32Big : PACK_WORD
    structure PackWord32Little : PACK_WORD
    structure PackWord64Big : PACK_WORD
    structure PackWord64Little : PACK_WORD
 end
```

Useless

Useless is an optimization pass for the SSA IntermediateLanguage, invoked from SSASimplify.

Description

This pass:

- removes components of tuples that are constants (use unification)
- removes function arguments that are constants
- builds some kind of dependence graph where
  - a value of ground type is useful if it is an arg to a primitive
  - a tuple is useful if it contains a useful component
  - a constructor is useful if it contains a useful component or is used in a `Case` transfer

If a useful tuple is coerced to another useful tuple, then all of their components must agree (exactly). It is trivial to convert a useful value to a useless one.

Implementation

- `useless.fun`

Details and Notes

It is also trivial to convert a useful tuple to one of its useful components — but this seems hard.

Suppose that you have a `ref`/`array`/`vector` that is useful, but the components aren't — then the components are converted to type `unit`, and any primitive args must be as well.

Unify all handler arguments so that `raise`/`handle` has a consistent calling convention.

Users

Here is a list of companies, projects, and courses that use or have used MLton. If you use MLton and are not here, please add your project with a brief description and a link. Thanks.

Companies

- Hardcore Processing uses MLton as a crosscompiler from Linux to Windows for graphics and game software.
  - CEX3D Converter, a conversion program for 3D objects.
  - Interactive Showreel, which contains a crossplatform GUI-toolkit and a realtime renderer for a subset of RenderMan written in Standard ML.
  - various games
- MathWorks/PolySpace Technologies builds their product that detects runtime errors in embedded systems based on abstract interpretation.
- Reactive Systems uses MLton to build Reactis, a model-based testing and validation package used in the automotive and aerospace industries.

Projects

- ADATE, Automatic Design of Algorithms Through Evolution, a system for automatic programming i.e., inductive inference of algorithms. ADATE can automatically generate non-trivial and novel algorithms written in Standard ML.
- CIL, a compiler for SML based on intersection and union types.
- ConCert, a project investigating certified code for grid computing.
- Cooperative Internet hosting tools
- Guugelhupf, a simple search engine.
- HaMLet, a model implementation of Standard ML.
- KeplerCode, independent verification of the computational aspects of proofs of the Kepler conjecture and the Dodecahedral conjecture.
- Metis, a first-order prover (used in the HOL4 theorem prover and the Isabelle theorem prover).
- mlftpd, an ftp daemon written in SML. TomMurphy is also working on replacements for standard network services in SML. He also uses MLton to build his entries (2001, 2002, 2004, 2005) in the annual ICFP programming contest.
- MLOPE, an offline partial evaluator for Standard ML.
- RML, a system for developing, compiling and debugging and teaching structural operational semantics (SOS) and natural semantics specifications.
- Skalpel, a type-error slicer for SML
- SSA PRE, an implementation of Partial Redundancy Elimination for MLton.
- Stabilizers, a modular checkpointing abstraction for concurrent functional programs.
- Self-Adjusting SML, self-adjusting computation, a model of computing where programs can automatically adjust to changes to their data.
- TL System, providing general-purpose support for rewrite-based transformation over elements belonging to a (user-defined) domain language.
- Tina (Time Petri net Analyzer)
- Twelf an implementation of the LF logical framework.
- WaveScript/WaveScript, a sensor network project; the WaveScript compiler can generate SML (MLton) code.

Courses

- Harvard CS-152, undergraduate programming languages.
- Høgskolen i Østfold IAI30202, programming languages.

Utilities

This page is a collection of basic utilities used in the examples on various pages. See

- InfixingOperators, and
- ProductType

for longer discussions on some of these utilities.

```
(* Operator precedence table *)
infix   8  * / div mod        (* +1 from Basis Library *)
infix   7  + - ^              (* +1 from Basis Library *)
infixr  6  :: @               (* +1 from Basis Library *)
infix   5  = <> > >= < <=     (* +1 from Basis Library *)
infix   4  <\ \>
infixr  4  </ />
infix   3  o
infix   2  >|
infixr  2  |<
infix   1  :=                 (* -2 from Basis Library *)
infix   0  before &

(* Some basic combinators *)
fun const x _ = x
fun cross (f, g) (x, y) = (f x, g y)
fun curry f x y = f (x, y)
fun fail e _ = raise e
fun id x = x

(* Product type *)
datatype ('a, 'b) product = & of 'a * 'b

(* Sum type *)
datatype ('a, 'b) sum = INL of 'a | INR of 'b

(* Some type shorthands *)
type 'a uop = 'a -> 'a
type 'a fix = 'a uop -> 'a
type 'a thunk = unit -> 'a
type 'a effect = 'a -> unit
type ('a, 'b) emb = ('a -> 'b) * ('b -> 'a)

(* Infixing, sectioning, and application operators *)
fun x <\ f = fn y => f (x, y)
fun f \> y = f y
fun f /> y = fn x => f (x, y)
fun x </ f = f x

(* Piping operators *)
val op>| = op</
val op|< = op\>
```

ValueRestriction

The value restriction is a rule that governs when type inference is allowed to polymorphically generalize a value declaration. In short, the value restriction says that generalization can only occur if the right-hand side of an expression is syntactically a value. For example, in

```
val f = fn x => x
val _ = (f "foo"; f 13)
```

the expression `fn x => x` is syntactically a value, so `f` has polymorphic type `'a -> 'a` and both calls to `f` type check. On the other hand, in

```
val f = let in fn x => x end
val _ = (f "foo"; f 13)
```

the expression `let in fn x => end end` is not syntactically a value and so `f` can either have type `int -> int` or `string -> string`, but not `'a -> 'a`. Hence, the program does not type check.

The Definition of Standard ML spells out precisely which expressions are syntactic values (it refers to such expressions as *non-expansive*). An expression is a value if it is of one of the following forms.

- a constant (`13`, `"foo"`, `13.0`, ...)
- a variable (`x`, `y`, ...)
- a function (`fn x => e`)
- the application of a constructor other than `ref` to a value (`Foo v`)
- a type constrained value (`v:t`)
- a tuple in which each field is a value `(v1, v2, ...)`
- a record in which each field is a value `{l1 =v1, l2 =v2, ...}`
- a list in which each element is a value `[v1, v2, ...]`

Why the value restriction exists

The value restriction prevents a ref cell (or an array) from holding values of different types, which would allow a value of one type to be cast to another and hence would break type safety. If the restriction were not in place, the following program would type check.

```
val r: 'a option ref = ref NONE
val r1: string option ref = r
val r2: int option ref = r
val () = r1 := SOME "foo"
val v: int = valOf (!r2)
```

The first line violates the value restriction because `ref NONE` is not a value. All other lines are type correct. By its last line, the program has cast the string `"foo"` to an integer. This breaks type safety, because now we can add a string to an integer with an expression like `v + 13`. We could even be more devious, by adding the following two lines, which allow us to threat the string `"foo"` as a function.

```
val r3: (int -> int) option ref = r
val v: int -> int = valOf (!r3)
```

Eliminating the explicit `ref` does nothing to fix the problem. For example, we could replace the declaration of `r` with the following.

```
val f: unit -> 'a option ref = fn () => ref NONE
val r: 'a option ref = f ()
```

The declaration of `f` is well typed, while the declaration of `r` violates the value restriction because `f ()` is not a value.

Unnecessarily rejected programs

Unfortunately, the value restriction rejects some programs that could be accepted.

```
val id: 'a -> 'a = fn x => x
val f: 'a -> 'a = id id
```

The type constraint on `f` requires `f` to be polymorphic, which is disallowed because `id id` is not a value. MLton reports the following type error.

```
Error: z.sml 2.5-2.5.
  Type of variable cannot be generalized in expansive declaration: f.
    type: ['a] -> ['a]
    in: val 'a f: ('a -> 'a) = id id
```

MLton indicates the inability to make `f` polymorphic by saying that the type of `f` cannot be generalized (made polymorphic) its declaration is expansive (not a value). MLton doesn't explicitly mention the value restriction, but that is the reason. If we leave the type constraint off of `f`

```
val id: 'a -> 'a = fn x => x
val f = id id
```

then the program succeeds; however, MLton gives us the following warning.

```
Warning: z.sml 2.5-2.5.
  Type of variable was not inferred and could not be generalized: f.
    type: ??? -> ???
    in: val f = id id
```

This warning indicates that MLton couldn't polymorphically generalize `f`, nor was there enough context using `f` to determine its type. This in itself is not a type error, but it it is a hint that something is wrong with our program. Using `f` provides enough context to eliminate the warning.

```
val id: 'a -> 'a = fn x => x
val f = id id
val _ = f 13
```

But attempting to use `f` as a polymorphic function will fail.

```
val id: 'a -> 'a = fn x => x
val f = id id
val _ = f 13
val _ = f "foo"
```

```
Error: z.sml 4.9-4.15.
  Function applied to incorrect argument.
    expects: [int]
    but got: [string]
    in: f "foo"
```

Alternatives to the value restriction

There would be nothing wrong with treating `f` as polymorphic in

```
val id: 'a -> 'a = fn x => x
val f = id id
```

One might think that the value restriction could be relaxed, and that only types involving `ref` should be disallowed. Unfortunately, the following example shows that even the type `'a -> 'a` can cause problems. If this program were allowed, then we could cast an integer to a string (or any other type).

```
val f: 'a -> 'a =
   let
      val r: 'a option ref = ref NONE
   in
      fn x =>
      let
         val y = !r
         val () = r := SOME x
      in
         case y of
            NONE => x
          | SOME y => y
      end
   end
val _ = f 13
val _ = f "foo"
```

The previous version of Standard ML took a different approach (MilnerEtAl90, Tofte90, ImperativeTypeVariable) than the value restriction. It encoded information in the type system about when ref cells would be created, and used this to prevent a ref cell from holding multiple types. Although it allowed more programs to be type checked, this approach had significant drawbacks. First, it was significantly more complex, both for implementers and for programmers. Second, it had an unfortunate interaction with the modularity, because information about ref usage was exposed in module signatures. This either prevented the use of references for implementing a signature, or required information that one would like to keep hidden to propagate across modules.

In the early nineties, Andrew Wright studied about 250,000 lines of existing SML code and discovered that it did not make significant use of the extended typing ability, and proposed the value restriction as a simpler alternative (Wright95). This was adopted in the revised Definition.

Working with the value restriction

One technique that works with the value restriction is EtaExpansion. We can use eta expansion to make our `id id` example type check follows.

```
val id: 'a -> 'a = fn x => x
val f: 'a -> 'a = fn z => (id id) z
```

This solution means that the computation (in this case `id id`) will be performed each time `f` is applied, instead of just once when `f` is declared. In this case, that is not a problem, but it could be if the declaration of `f` performs substantial computation or creates a shared data structure.

Another technique that sometimes works is to move a monomorphic computation prior to a (would-be) polymorphic declaration so that the expression is a value. Consider the following program, which fails due to the value restriction.

```
datatype 'a t = A of string | B of 'a
val x: 'a t = A (if true then "yes" else "no")
```

It is easy to rewrite this program as

```
datatype 'a t = A of string | B of 'a
local
   val s = if true then "yes" else "no"
in
   val x: 'a t = A s
end
```

The following example (taken from Wright95) creates a ref cell to count the number of times a function is called.

```
val count: ('a -> 'a) -> ('a -> 'a) * (unit -> int) =
   fn f =>
   let
```

```
      val r = ref 0
   in
      (fn x => (r := 1 + !r; f x), fn () => !r)
   end
val id: 'a -> 'a = fn x => x
val (countId: 'a -> 'a, numCalls) = count id
```

The example does not type check, due to the value restriction. However, it is easy to rewrite the program, staging the ref cell creation before the polymorphic code.

```
datatype t = T of int ref
val count1: unit -> t = fn () => T (ref 0)
val count2: t * ('a -> 'a) -> (unit -> int) * ('a -> 'a) =
   fn (T r, f) => (fn () => !r, fn x => (r := 1 + !r; f x))
val id: 'a -> 'a = fn x => x
val t = count1 ()
val countId: 'a -> 'a = fn z => #2 (count2 (t, id)) z
val numCalls = #1 (count2 (t, id))
```

Of course, one can hide the constructor `T` inside a `local` or behind a signature.

Also see

- ImperativeTypeVariable

VariableArityPolymorphism

Standard ML programmers often face the problem of how to provide a variable-arity polymorphic function. For example, suppose one is defining a combinator library, e.g. for parsing or pickling. The signature for such a library might look something like the following.

```
signature COMBINATOR =
   sig
      type 'a t

      val int: int t
      val real: real t
      val string: string t
      val unit: unit t
      val tuple2: 'a1 t * 'a2 t -> ('a1 * 'a2) t
      val tuple3: 'a1 t * 'a2 t * 'a3 t -> ('a1 * 'a2 * 'a3) t
      val tuple4: 'a1 t * 'a2 t * 'a3 t * 'a4 t
                  -> ('a1 * 'a2 * 'a3 * 'a4) t
      ...
   end
```

The question is how to define a variable-arity tuple combinator. Traditionally, the only way to take a variable number of arguments in SML is to put the arguments in a list (or vector) and pass that. So, one might define a tuple combinator with the following signature.

```
val tupleN: 'a list -> 'a list t
```

The problem with this approach is that as soon as one places values in a list, they must all have the same type. So, programmers often take an alternative approach, and define a family of `tuple<N>` functions, as we see in the `COMBINATOR` signature above.

The family-of-functions approach is ugly for many reasons. First, it clutters the signature with a number of functions when there should really only be one. Second, it is *closed*, in that there are a fixed number of tuple combinators in the interface, and should a client need a combinator for a large tuple, he is out of luck. Third, this approach often requires a lot of duplicate code in the implementation of the combinators.

Fortunately, using Fold01N and products, one can provide an interface and implementation that solves all these problems. Here is a simple pickling module that converts values to strings.

```
structure Pickler =
   struct
      type 'a t = 'a -> string

      val unit = fn () => ""

      val int = Int.toString

      val real = Real.toString

      val string = id

      type 'a accum = 'a * string list -> string list

      val tuple =
         fn z =>
         Fold01N.fold
         {finish = fn ps => fn x => concat (rev (ps (x, []))),
          start = fn p => fn (x, l) => p x :: l,
          zero = unit}
         z

      val ` =
```

```
         fn z =>
         Fold01N.step1
         {combine = (fn (p, p') => fn (x & x', l) => p' x' :: "," :: p (x, l))}
         z
   end
```

If one has `n` picklers of types

```
val p1: a1 Pickler.t
val p2: a2 Pickler.t
...
val pn: an Pickler.t
```

then one can construct a pickler for n-ary products as follows.

```
tuple `p1 `p2 ... `pn $ : (a1 & a2 & ... & an) Pickler.t
```

For example, with `Pickler` in scope, one can prove the following equations.

```
"" = tuple $ ()
"1" = tuple `int $ 1
"1,2.0" = tuple `int `real $ (1 & 2.0)
"1,2.0,three" = tuple `int `real `string $ (1 & 2.0 & "three")
```

Here is the signature for `Pickler`. It shows why the `accum` type is useful.

```
signature PICKLER =
   sig
      type 'a t

      val int: int t
      val real: real t
      val string: string t
      val unit: unit t

      type 'a accum
      val ` : ('a accum, 'b t, ('a, 'b) prod accum,
               'z1, 'z2, 'z3, 'z4, 'z5, 'z6, 'z7) Fold01N.step1
      val tuple: ('a t, 'a accum, 'b accum, 'b t, unit t,
                  'z1, 'z2, 'z3, 'z4, 'z5) Fold01N.t
   end

structure Pickler: PICKLER = Pickler
```

Variant

A *variant* is an arm of a datatype declaration. For example, the datatype

```
datatype t = A | B of int | C of real
```

has three variants: `A`, `B`, and `C`.

VesaKarvonen

Vesa Karvonen is a student at the University of Helsinki. His interests lie in programming techniques that allow complex programs to be expressed clearly and concisely and the design and implementation of programming languages.

Things he'd like to see for SML and hopes to be able to contribute towards:

- A practical tool for documenting libraries. Preferably one that is based on extracting the documentation from source code comments.
- A good IDE. Possibly an enhanced SML mode (`esml-mode`) for Emacs. Google for SLIME video to get an idea of what he'd like to see. Some specific notes:
  - show type at point
  - robust, consistent indentation
  - show documentation
  - jump to definition (see EmacsDefUseMode)

  EmacsBgBuildMode has also been written for working with MLton.
- Documented and cataloged libraries. Perhaps something like Boost, but for SML libraries. Here is a partial list of libraries, tools, and frameworks Vesa is or has been working on:
  - Asynchronous Programming Library (`README`)
  - Extended Basis Library (`README`)

- Generic Programming Library (README)
- Pretty Printing Library (README)
- Random Generator Library (README)
- RPC (Remote Procedure Call) Library (README)
- SDL Binding (README)
- Unit Testing Library (README)
- Use Library (README)
- Windows Library (README)

Note that most of these libraries have been ported to several SML implementations.

WarnUnusedAnomalies

The `warnUnused` MLBasis annotation can be used to report unused identifiers. This can be useful for catching bugs and for code maintenance (e.g., eliminating dead code). However, the `warnUnused` annotation can sometimes behave in counter-intuitive ways. This page gives some of the anomalies that have been reported.

- Functions whose only uses are recursive uses within their bodies are not warned as unused:

```
local
fun foo () = foo () : unit
val bar = let fun baz () = baz () : unit in baz end
in
end
```

```
Warning: z.sml 3.5.
  Unused variable: bar.
```

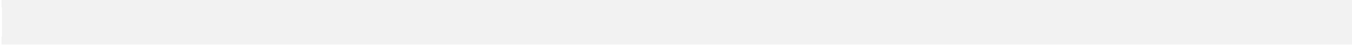
- Components of actual functor argument that are necessary to match the functor argument signature but are unused in the body of the functor are warned as unused:

```
functor Warning (type t val x : t) = struct
   val y = x
end
structure X = Warning (type t = int val x = 1)
```

```
Warning: z.sml 4.29.
  Unused type: t.
```

- No component of a functor result is warned as unused. In the following, the only uses of `f2` are to match the functor argument signatures of `functor G` and `functor H` and there are no uses of `z`:

```
functor F(structure X : sig type t end) = struct
   type t = X.t
   fun f1 (_ : X.t) = ()
   fun f2 (_ : X.t) = ()
   val z = ()
end
functor G(structure Y : sig
                           type t
                           val f1 : t -> unit
                           val f2 : t -> unit
                           val z : unit
                        end) = struct
   fun g (x : Y.t) = Y.f1 x
end
functor H(structure Y : sig
                           type t
                           val f1 : t -> unit
                           val f2 : t -> unit
                           val z : unit
                        end) = struct
   fun h (x : Y.t) = Y.f1 x
end
functor Z() = struct
   structure S = F(structure X = struct type t = unit end)
   structure SG = G(structure Y = S)
   structure SH = H(structure Y = S)
end
structure U = Z()
val _ = U.SG.g ()
val _ = U.SH.h ()
```



WesleyTerpstra

Wesley W. Terpstra is a PhD student at the Technische Universitat Darmstadt (Germany).

Research interests

- Distributed systems (P2P)
- Number theory (Error-correcting codes)

My interest in SML is centered on the fact the the language is able to directly express ideas from number theory which are important for my work. Modules and Functors seem to be a very natural basis for implementing many algebraic structures. MLton provides an ideal platform for actual implementation as it is fast and has unboxed words.

Things I would like from MLton in the future:

- Some better optimization of mathematical expressions
- IPv6 and multicast support
- A complete GUI toolkit like mGTK
- More supported platforms so that applications written under MLton have a wider audience

WholeProgramOptimization

Whole-program optimization is a compilation technique in which optimizations operate over the entire program. This allows the compiler many optimization opportunities that are not available when analyzing modules separately (as with separate compilation).

Most of MLton's optimizations are whole-program optimizations. Because MLton compiles the whole program at once, it can perform optimization across module boundaries. As a consequence, MLton often reduces or eliminates the run-time penalty that arises with separate compilation of SML features such as functors, modules, polymorphism, and higher-order functions. MLton takes advantage of having the entire program to perform transformations such as: defunctorization, monomorphisation, higher-order control-flow analysis, inlining, unboxing, argument flattening, redundant-argument removal, constant folding, and representation selection. Whole-program compilation is an integral part of the design of MLton and is not likely to change.

WishList

This page is mainly for recording recurring feature requests. If you have a new feature request, you probably want to query interest on one of the mailing lists first.

Please be aware of MLton's policy on language changes. Nonetheless, we hope to provide support for some of the "immediate" SuccessorML proposals in a future release.

Support for link options in ML Basis files

Introduce a mechanism to specify link options in ML Basis files. For example, generalizing a bit, a ML Basis declaration of the form

```
option "option"
```

could be introduced whose semantics would be the same (as closely as possible) as if the option string were specified on the compiler command line.

The main motivation for this is that a MLton library that would introduce bindings (through FFI) to an external library could be packaged conveniently as a single MLB file. For example, to link with library `foo` the MLB file would simply contain:

```
option "-link-opt -lfoo"
```

Similar feature requests have been discussed previously on the mailing lists:

- http://www.mlton.org/pipermail/mlton/2004-July/025553.html
- http://www.mlton.org/pipermail/mlton/2005-January/026648.html

XML

XML is an IntermediateLanguage, translated from CoreML by Defunctorize, optimized by XMLSimplify, and translated by Monomorphise to SXML.

Description

XML is polymorphic, higher-order, with flat patterns. Every XML expression is annotated with its type. Polymorphic generalization is made explicit through type variables annotating `val` and `fun` declarations. Polymorphic instantiation is made explicit by specifying type arguments at variable references. XML patterns can not be nested and can not contain wildcards, constraints, flexible records, or layering.

Implementation

- `xml.sig`
- `xml.fun`
- `xml-tree.sig`
- `xml-tree.fun`

Type Checking

XML also has a type checker, used for debugging. At present, the type checker is also the best specification of the type system of XML. If you need more details, the type checker (`type-check.sig`, `type-check.fun`), is pretty short.

Since the type checker does not affect the output of the compiler (unless it reports an error), it can be turned off. The type checker recursively descends the program, checking that the type annotating each node is the same as the type synthesized from the types of the expressions subnodes.

Details and Notes

XML uses the same atoms as CoreML, hence all identifiers (constructors, variables, etc.) are unique and can have properties attached to them. Finally, XML has a simplifier (XMLShrink), which implements a reduction system.

Types

XML types are either type variables or applications of n-ary type constructors. There are many utility functions for constructing and destructing types involving built-in type constructors.

A type scheme binds list of type variables in a type. The only interesting operation on type schemes is the application of a type scheme to a list of types, which performs a simultaneous substitution of the type arguments for the bound type variables of the scheme. For the purposes of type checking, it is necessary to know the type scheme of variables, constructors, and primitives. This is done by associating the scheme with the identifier using its property list. This approach is used instead of the more traditional environment approach for reasons of speed.

XmlTree

Before defining `XML`, the signature for language XML, we need to define an auxiliary signature `XML_TREE`, that contains the datatype declarations for the expression trees of XML. This is done solely for the purpose of modularity — it allows the simplifier and type checker to be defined by separate functors (which take a structure matching `XML_TREE`). Then, `Xml` is defined as the signature for a module containing the expression trees, the simplifier, and the type checker.

Both constructors and variables can have type schemes, hence both constructor and variable references specify the instance of the scheme at the point of references. An instance is specified with a vector of types, which corresponds to the type variables in the scheme.

XML patterns are flat (i.e. not nested). A pattern is a constructor with an optional argument variable. Patterns only occur in `case` expressions. To evaluate a case expression, compare the test value sequentially against each pattern. For the first pattern that matches, destruct the value if necessary to bind the pattern variables and evaluate the corresponding expression. If no pattern matches, evaluate the default. All patterns of a case statement are of the same variant of `Pat.t`, although this is not enforced by ML's type system. The type checker, however, does enforce this. Because tuple patterns are irrefutable, there will only ever be one tuple pattern in a case expression and there will be no default.

XML contains value, exception, and mutually recursive function declarations. There are no free type variables in XML. All type variables are explicitly bound at either a value or function declaration. At some point in the future, exception declarations may go away, and exceptions may be represented with a single datatype containing a `unit ref` component to implement genericity.

XML expressions are like those of CoreML, with the following exceptions. There are no records expressions. After type inference, all records (some of which may have originally been tuples in the source) are converted to tuples, because once flexible record patterns have been resolved, tuple labels are superfluous. Tuple components are ordered based on the field ordering relation. XML eta expands primitives and constructors so that there are always fully applied. Hence, the only kind of value of arrow type is a lambda. This property is useful for flow analysis and later in code generation.

An XML program is a list of toplevel datatype declarations and a body expression. Because datatype declarations are not generative, the defunctorizer can safely move them to toplevel.

XMLShrink

XMLShrink is an optimization pass for the XML IntermediateLanguage, invoked from XMLSimplify.

Description

This pass performs optimizations based on a reduction system.

Implementation

- shrink.sig
- shrink.fun

Details and Notes

The simplifier is based on Shrinking Lambda Expressions in Linear Time.

The source program may contain functions that are only called once, or not even called at all. Match compilation introduces many such functions. In order to reduce the program size, speed up later phases, and improve the flow analysis, a source to source simplifier is run on XML after type inference and match compilation.

The simplifier implements the reductions shown below. The reductions eliminate unnecessary declarations (see the side constraint in the figure), applications where the function is immediate, and case statements where the test is immediate. Declarations can be eliminated only when the expression is nonexpansive (see Section 4.7 of the Definition), which is a syntactic condition that ensures that the expression has no effects (assignments, raises, or nontermination). The reductions on case statements do not show the other irrelevant cases that may exist. The reductions were chosen so that they were strongly normalizing and so that they never increased tree size.

- ```
  let x = e1 in e2
  ```

  reduces to

  ```
  e2 [x -> e1]
  ```

  if `e1` is a constant or variable or if `e1` is nonexpansive and `x` occurs zero or one time in `e2`

- ```
  (fn x => e1) e2
  ```

  reduces to

  ```
  let x = e2 in e1
  ```

- ```
  e1 handle e2
  ```

  reduces to

  ```
  e1
  ```

  if `e1` is nonexpansive

- ```
  case let d in e end of p1 => e1 ...
  ```

  reduces to

  ```
  let d in case e of p1 => e1 ... end
  ```

- ```
  case C e1 of C x => e2
  ```

  reduces to

  ```
  let x = e1 in e2
  ```
  ```

XMLSimplify

The optimization passes for the XML IntermediateLanguage are collected and controlled by the `XmlSimplify` functor (`xml-simplify.sig`, `xml-simplify.fun`).

The following optimization passes are implemented:

- XMLSimplifyTypes
- XMLShrink

The optimization passes can be controlled from the command-line by the options

- `-diag-pass <pass>` — keep diagnostic info for pass
- `-disable-pass <pass>` — skip optimization pass (if normally performed)
- `-enable-pass <pass>` — perform optimization pass (if normally skipped)
- `-keep-pass <pass>` — keep the results of pass
- `-xml-passes <passes>` — xml optimization passes

XMLSimplifyTypes

XMLSimplifyTypes is an optimization pass for the XML IntermediateLanguage, invoked from XMLSimplify.

Description

This pass simplifies types in an XML program, eliminating all unused type arguments.

Implementation

- `simplify-types.sig`
- `simplify-types.fun`

Details and Notes

It first computes a simple fixpoint on all the `datatype` declarations to determine which `datatype` `tycon` args are actually used. Then it does a single pass over the program to determine which polymorphic declaration type variables are used, and rewrites types to eliminate unused type arguments.

This pass should eliminate any spurious duplication that the Monomorphise pass might perform due to phantom types.

Zone

Zone is an optimization pass for the SSA2 IntermediateLanguage, invoked from SSA2Simplify.

Description

This pass breaks large SSA2 functions into zones, which are connected subgraphs of the dominator tree. For each zone, at the node that dominates the zone (the "zone root"), it places a tuple collecting all of the live variables at that node. It replaces any variables used in that zone with offsets from the tuple. The goal is to decrease the liveness information in large SSA functions.

Implementation

- `zone.fun`

Details and Notes

Compute strongly-connected components to avoid put tuple constructions in loops.

There are two (expert) flags that govern the use of this pass

- `-max-function-size <n>`
- `-zone-cut-depth <n>`

Zone splitting only works when the number of basic blocks in a function is greater than `n`. The `n` used to cut the dominator tree is set by `-zone-cut-depth`.

There is currently no attempt to be safe-for-space. That is, the tuples are not restricted to containing only "small" values.

In the `HOL` program, the particular problem is the main function, which has 161,783 blocks and 257,519 variables — the product of those two numbers being about 41 billion. Now, we're not likely going to need that much space since we use a sparse representation. But even 1/100th would really hurt. And of course this rules out bit vectors.

ZZZOrphanedPages

The contents of these pages have been moved to other pages.

These templates are used by other pages.

- CompilerPassTemplate
- TalkTemplate