GNU Modula-2 status, whole program optimisation and language interoperability

Gaius Mulley
<gaius@gnu.org>

Department of Computer Science
University of South Wales
CF37 1DL
Why Modula-2 today?

- “source code which cannot port to another architecture will die”
  Mike Gancarz

- legacy code
  - academic
  - industrial

- embedded systems of today
  - low memory footprint, bit manipulation, memory mapped variables, coroutines, interrupt priorities

- great teaching language
Embedded systems and Modula-2

- The microprocessor is an ATmega328p
- 32 KB of flash memory and 2 KB of RAM (£ 1.00)
About GNU Modula-2

- GNU Modula-2 supports PIM2, PIM3, PIM4 and ISO Modula-2

- PIM support was finished in 2006

- ISO libraries and language were completed in 2010

- dejagnu regression testsuite
  - 1670 individual tests
  - run multiple times with varying command line options

- the front end, libraries and testsuite are all GPL 3.0
development started in 1999 after receiving an email from rms

initially borrowed much code from m2f (now renamed x86_m2) written in 1992 (PIM2 compiler)

it also had a -students option, which performed semantic checking on legal but poor code:
  - declaring variables using keyword names, variables using same name different case in the same scope
  - typically trying to guide first year programming students to use better coding style
the current stable release is gcc-4.7.4+gm2-1.1.5.tar.gz which is available from [http://www.nongnu.org/gm2/download.html](http://www.nongnu.org/gm2/download.html)
Current development

- focused on gcc-5.2.0 (gcc-5.3.0 and trunc).
- in particular in the last 9 months the bootstrapping has undergone a huge change
  - p2c has been really useful over the past 24 years
    - p2c has been replaced by mc
  - mc borrowed the parser and approx 25 implementation modules from gm2
  - unlike p2c, mc understands full Modula-2 syntax and GNU Modula-2 extensions
    - no forward references required
Current development

- p2c required too many changes to enable it to generate g++ compliant C

- mc was completed this week and it will be used to bootstrap gm2

- the rewritten modules in mc will be back-ported to gm2

- initiating a partial rewrite of gm2
Observations

- whenever a change occurs in GCC which effects a front end it nearly always results in a cleaner front end!

- the argument handling changes from a few years ago also caused tidying of the code base

- introduction of gimple interface in the 4.1.2 era tidied up code

- the move to building with g++ caused, in part, mc to be constructed

- in turn this has shown the gm2 code base from the 4.7.4 era to look a little old
Features

- GNU Modula-2 implements all dialects of Modula-2 PIM2, PIM3, PIM4, ISO and supporting libraries

- it tries to follow the GCC ethos of extensions:
  - ASM is exactly the same as C/C++ etc
  - `-fcpp` runs the C preprocessor over the source using the `cpp -lang-asm -traditional-cpp` option (aka GNU Fortran)
Extensions to allow access to C libraries

```plaintext
DEFINITION MODULE FOR "C" libc ;
EXPORT UNQUALIFIED printf ;
PROCEDURE printf (format: ARRAY OF CHAR; ...) : [ INTEGER ] ;
END libc.
```

- optional return value, strings passed by address and varargs

- when using DEFINITION MODULE FOR "C" pointers are mapped onto: SYSTEM.ADDRESS
  - ARRAY OF type is mapped onto type *
  - all other types are mapped onto their C counterparts
PROCEDURE Example (i, j: CARDINAL) : CARDINAL ;
VAR
  k: CARDINAL ;
BEGIN
  ASM VOLATILE ("movl %1,%eax; \naddl %2,%eax; movl %eax,%0"
    : "=g" (k)  (* outputs *)
    : "g" (i), "g" (j) (* inputs *)
    : "eax") ; (* we trash *)
  RETURN( k )
END Example ;
Extensions: access to GCC built-ins

- access to *alloca*, *memcpy*, *sin* and friends

```
DEFINITION MODULE MathLib0 ;

CONST
   pi =3.1415926535897932384626433832795028841972;
   exp1=2.7182818284590452353602874713526624977572;

PROCEDURE __BUILTIN__ sqrt (x: REAL) : REAL ;
PROCEDURE __BUILTIN__ sin (x: REAL) : REAL ;
PROCEDURE __BUILTIN__ cos (x: REAL) : REAL ;
PROCEDURE tan (x: REAL) : REAL ;
```
Extensions: access to GCC built-ins

```plaintext
IMPLEMENTATION MODULE MathLib0 ;

IMPORT cbuiltin;

PROCEDURE __ATTRIBUTE__ __BUILTIN__ ((__builtin_sqrt))
    sqrt (x: REAL): REAL;
BEGIN
    RETURN cbuiltin.sqrt (x)
END sqrt ;
```
Language extensions

- enhances a number of language features:
  - sets can be declared from any ordinal type
  - abstract data types are not restricted to a pointer type
  - types, variables, constants, may be declared in any order
    - technically not a language extension but gm2 does not need forward declarations
-fswig generates a interface file, gm2 will examine the procedure parameters and attempt to work out the input/output parameters

works reasonably well and in a couple of command lines will allow Python to call Modula-2

can throw an exception in Modula-2 and catch it in Python (or another scripting language)
Mixed language support

- Likewise, a C++ module can throw an exception and Modula-2 can catch it.

- `libtool` is supported, can be used to build shared libraries.
Mixed language support

gcc-version/gcc/gm2/examples/pge/Make-file.in

```bash
swig -outdir . -o pgeif_wrap.cxx -c++ -python $(srcdir)/pgeif.i
libtool --tag=CC --mode=compile g++ -g -c pgeif_wrap.cxx \
  -I/usr/include/python$(PYTHON_VERSION) -o pgeif_wrap.lo
gm2 -c -g -I$(SRC_PATH_PIM) -fmakelist $(srcdir)/pgeif.mod
gm2 -c -g -I$(SRC_PATH_PIM) -fmakeinit -fshared $(srcdir)/pgeif.mod
libtool --tag=CC --mode=compile g++ -g -c _m2_pgeif.cpp \
  -o _m2_pgeif.lo
libtool --tag=CC --mode=link gcc -g _m2_pgeif.lo \n  $(PGELIBSOURCES:%.mod=%.lo) \n  pgeif_wrap.lo buffers.lo \n  -L$(prefix)/lib64 \n  -rpath `pwd` -lgm2 -liso -lgcc -lstdc++ -lpth -lc \n  -lm -o libpgeif.la
cp .libs/libpgeif.so _pgeif.so
```

libtool is also used when multiarch building the PIM, ISO, LogiTech compatible, Ulm, Min, Coroutines libraries (gcc-version/libgm2)
## Data type correspondence with C/C++

<table>
<thead>
<tr>
<th>GNU Modula-2</th>
<th>GNU C</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTEGER</td>
<td>int</td>
</tr>
<tr>
<td>LONGINT</td>
<td>long long int</td>
</tr>
<tr>
<td>SHORTINT</td>
<td>short int</td>
</tr>
<tr>
<td>CARDINAL</td>
<td>unsigned int</td>
</tr>
<tr>
<td>LONGCARD</td>
<td>long long unsigned int</td>
</tr>
<tr>
<td>SHORTCARD</td>
<td>short unsigned int</td>
</tr>
<tr>
<td>BITSET</td>
<td>unsigned int</td>
</tr>
<tr>
<td>BOOLEAN</td>
<td>int</td>
</tr>
<tr>
<td>REAL</td>
<td>double</td>
</tr>
<tr>
<td>LONGREAL</td>
<td>long double</td>
</tr>
<tr>
<td>SHORTREAL</td>
<td>float</td>
</tr>
<tr>
<td>CHAR</td>
<td>char</td>
</tr>
<tr>
<td>SHORTCOMPLEX</td>
<td>complex float</td>
</tr>
<tr>
<td>COMPLEX</td>
<td>complex double</td>
</tr>
<tr>
<td>LONGCOMPLEX</td>
<td>complex long double</td>
</tr>
</tbody>
</table>
Embedded system support

- ASM keyword supported as per GNU C
- Options to turn off exception handling and link against minimal runtime libraries

```bash
$ avr-gm2 -mmcu=atmega328 -g -Os -fno-exceptions -O2 -c \ 
  flashed328.mod -flibs=min
$ avr-gm2 -mmcu=atmega328 -g -Os -fno-exceptions -O2 \ 
  -fno-pth -fonlylink flashed328.mod -flibs=min -o flashed328.elf

$ avr-size flashed328.elf
  text  data  bss  dec  hex  filename
  370   0   0  370  172  flashed328.elf
```

- Users can specify the initialisation order of modules which are statically calculated via import lists and dependancies
Embedded system support

- request the initialisation list, modify it and continue to use this during the link

- used to create the main scaffold (in either C or C++)
Implementing unbounded arrays using trees

PROCEDURE concat (VAR a: ARRAY OF CHAR;
                   b: ARRAY OF CHAR) ;
VAR
  i: CARDINAL ;
BEGIN
  i := HIGH(a) ;
  a[0] := 'a' ;
  a[i] := 'b'

gm2 implements unbounded arrays by internally creating an unbounded type:

unbounded = RECORD
  _arrayAddress: POINTER TO arrayType ;
  _arrayHigh    : CARDINAL ;
END ;
Implementing unbounded arrays using trees

- callee must save contents of an array for each non VAR parameter
- achieved using memcpy and alloca

```
gcc-version/gcc/gm2/gm2-compiler/M2GenGCC.mod:MakeCoptAndUse

High := GetSizeOfHighFromUnbounded(tokenno, param);
Addr := GetAddressOfUnbounded(param);
Type := Mod2Gcc(GetType(param));

NewArray := BuiltinAlloca(location, High);
NewArray := BuiltinMemcpy(location, NewArray, Addr, High);

(* now assign  param.Addr := ADR(NewArray). *)
BuildAssignmentTree(location,
  BuildComponentRef(Mod2Gcc(param),
  Mod2Gcc(GetUnboundedAddressOffset(UnboundedType)),
  NewArray))
```

- due to in-lining of alloca and memcpy good code is emitted
The GNU Modula-2 front end is written in C and Modula-2

- uses `flex` and a Modula-2 parser generator to construct a top down recursive descent parser with error recovery
  - uses flex to build a dynamic buffer of all source tokens

- a six pass compiler which uses double entry book keeping
  - lexical analysis, parsing, modules and associated filenames
  - scopes, enumerated types, imports and exports
  - constants and types
  - [aggregate constants]
  - quadruple generation
  - gcc tree generation
The GNU Modula-2 front end is written in C and Modula-2

- each front end Modula-2 symbol table entry is translated into trees
- and finally the quadruples are translated into trees
- front end ensures that only legal symbols and legal source are ever passed to GCC
Compiler options

- **-Wstudents**
  - checks for bad programming style

- **-Wpedantic**
  - reject nested `WITH` statements referring to the same record type
  - reject code which uses a `FOR` loop indice outside the loop without being reset

- **-Wpedantic-param-names**
  - check definition module parameter names match their implementation counterparts

- **-fextended-opaque**
  - opaque types can be implemented as any type
  - also enables full type declaration to the debugger
Compiler options

- `fsoft-check-all` turns on `-fnil, -frange, -findex, -fwholediv, -fcase` and `-freturn`.

- `-fno-exceptions` ensure no references are generated to the exception libraries

- `-fiso, -fpim2, -fpim3, -fpim4`

for the complete list visit [http://www.nongnu.org/gm2/homepage.html](http://www.nongnu.org/gm2/homepage.html)
Whole program optimisation

credit to David Edelsohn (at the GCC Cauldron 2014 in Cambridge)

interesting to note that it took about 3 weeks to implement whole program improvement, should have done this long ago as the improvement was substantial for the minimal coding effort

all following timings were taken on Debian Jessie GNU/Linux AMD FX(tm)-8350 Eight-Core Processor, 4GHz, using gm2-1.1.5, gm2 (GCC) 4.7.4
Whole program optimisation

- maze generator compiled with `-O3`

<table>
<thead>
<tr>
<th>component</th>
<th>seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>real</td>
<td>2.511</td>
</tr>
<tr>
<td>user</td>
<td>2.508</td>
</tr>
</tbody>
</table>

- compiled with `-O3 -fno-whole-program`

<table>
<thead>
<tr>
<th>time ./map.whole &gt; m1.whole</th>
</tr>
</thead>
<tbody>
<tr>
<td>real</td>
</tr>
<tr>
<td>user</td>
</tr>
</tbody>
</table>

- 44% reduction in user time
Whole program optimisation

- physics game engine compiled with `-O3`
  
<table>
<thead>
<tr>
<th>time ./pge &gt; /dev/null</th>
</tr>
</thead>
<tbody>
<tr>
<td>real: 10.330</td>
</tr>
<tr>
<td>user: 6.880</td>
</tr>
<tr>
<td>sys: 3.440</td>
</tr>
</tbody>
</table>

- physics game engine compiled with `-O3 -fm2-whole-program`
  
<table>
<thead>
<tr>
<th>time ./pge-whole &gt; /dev/null</th>
</tr>
</thead>
<tbody>
<tr>
<td>real: 8.875</td>
</tr>
<tr>
<td>user: 5.428</td>
</tr>
<tr>
<td>sys: 3.440</td>
</tr>
</tbody>
</table>

- 22% reduction in user time, 14% reduction in real time
Immediate future

- complete graft onto gcc-5.2.0

- and track trunc

- current open branches in gm2 are:
  - gcc-4.1.2, gcc-4.7.4, gcc-5.2.0, gcc-5.3.0, and trunc
Future work

- implement -fwholevalue
- detect integer overflow at runtime

- prepare the source tree to implement M2R10
- 2010 revision of Modula-2 which is being standardised


[http://modula-2.info/m2r10/pmwiki.php/Project/FAQ]
## GNU Modula-2 code comparison on the gcc-4.7.4 branch

<table>
<thead>
<tr>
<th>Category under gcc-4.7.4</th>
<th>Lines (wc -l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>gcc/*.ch</td>
<td>787,368</td>
</tr>
<tr>
<td>gcc/fortran/*.ch</td>
<td>155,499</td>
</tr>
<tr>
<td>ada/*.ads,adb</td>
<td>1,031,376</td>
</tr>
<tr>
<td>gcc/gm2/*.def,mod</td>
<td>157,189</td>
</tr>
<tr>
<td>gcc/gm2/*.ch</td>
<td>27257</td>
</tr>
</tbody>
</table>
Conclusions and acknowledgements

- double entry bookkeeping is pragmatic and works well

- whole program optimisation should not be an after thought for a GCC front end
  - the gains are too good and coding effort is small

- huge thanks to
  - all GCC developers for great target architecture coverage
  - all gm2 users for all their feedback, bug reports and test programs