Easily coding a GCC extension with MELT

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What is MELT?

- in Debian, `melt` = command line media player and video editor. `http://www.mltframework.org`
- for LaTeX and Ocaml[1] users, Melt (by Romain Bardou) allows you to program LaTeX documents using `ocaml` `http://melt.forge.ocamlcore.org/`
- in GCC, MELT is an infrastructure and a **domain specific language** to ease development of specific GCC extensions **www.gcc-melt.org** and `http://gcc.gnu.org/wiki/MELT`

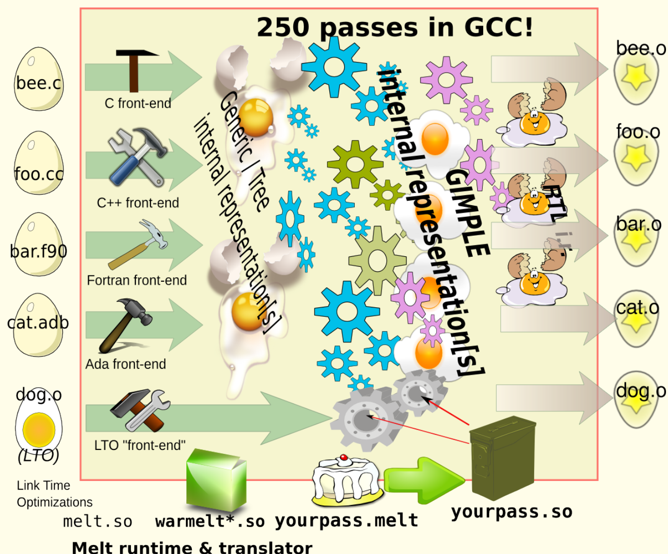
This talk is about GCC MELT ☺

MELT ≡ ***M****iddle* ***E****nd* ***L****isp* ***T****ranslator*

but MELT is perhaps not only for the middle-end!

[1] `http://caml.inria.fr/`

The big GCC MELT picture



GCC MELT

About these slides

- All **opinions are only mine**, not of: my employer (CEA, LIST)[2], funding agency (DGCIS)[3], my collegues or interns, or the GCC community.
- Some slides, in particular this one, are **extra slides** and may be skipped. They are pinky, and are **marked** with a ♠ at the bottom.
- These slides are made with Pdf LaTeX and beamer[4]
- The **MELT examples are really run** when producing the slides.
- These slides are available (in PDF) on **`www.gcc-melt.org`** site and attached to `http://gcc.gnu.org/wiki/MELT`
- syntax colorization with `pygments`, *minted* style, `contrib/pygmentize-melt`[5] script.

[2] `www-list.cea.fr`
[3] `www.industrie.gouv.fr/portail/une/dgcis.html`
[4] using `-shell-escape` but sadly without Romain Bardou's Melt
[5] Some bugs remain in that script, in particular for `$var`-s in macro-strings, e.g. code chunks

Expected audience

1. using GCC to compile important or big [free] software[6]
2. able to compile newest GCC from its source code
3. interested in extending or hacking GCC[7]
4. somehow **familiar with GCC internals** :
   - overall organization: driver, front-ends, middle-end, back-ends
   - major internal representations: Generic/Tree, Gimple, . . .
   - the many ($\approx$ 250) passes inside GCC
   - knowledgable of the GCC **plugins machinery**
5. pragmatically curious about domain specific or scripting languages
6. not necessarily familiar with lisp dialect[8], but not scared of parenthesis ☺

[6] MELT is probably overkill to compile `hello-world.c`

[7] Or even wanting to contribute to GCC MELT

[8] But small knoweldge of Scheme, Emacs-Lisp, or Common Lisp can help!

Questions to the audience

1. who coded a middle-end pass in GCC?
2. who knows some “functional / applicative” language, e.g. Ocaml, Haskell, Ruby, Python, Scala, Clojure . . . and used anonymous functions (λ-calculus)?
3. who knows (and did code) lispy languages, i.e. Scheme, Common Lisp, Emacs Lisp?
4. who knows about pattern matching?
5. who coded a GCC plugin?

To learn more about GCC ...

- lots of web resources **gcc.gnu.org**, and help of GCC community
- internal GCC documentations and source code availability
- major internal representations:
  - Generic/**Tree** (AST = abstract syntax tree), see `gcc/tree.def` and `gcc/tree.h` source files, "`union`" of $\approx$ 180 cases.
  - **Gimple** mostly "3 address" instructions (with Tree operands), see `gcc/gimple.def` and `gcc/gimple.h` files, "`union`" of $\approx$ 36 cases.
  - etc ...
- organization of **passes**:
  - used set of passes depends of optimization (and of source code)
  - see `gcc/tree-passes.c` file
  - run `gcc -fdump-tree-all`
  - your extension usually add some [your own] passes[9]
- GCC has a garbage collector Ggc [`GTY` annotations processed by `gengtype`] and MELT strongly depends upon it

[9] Finding what pass to add and where is tricky!

When you shouldn't use MELT

- if you cannot have and build plugins on your GCC compiler
- if your computer is too small to build GCC[10]
- to develop core GCC (trunk) enhancements (to be pushed inside `gcc`)
  - you can't use MELT since it is a plugin[11] and a non-standard language!
  - but you can **prototype** your work **with MELT** and **experiment new ideas with MELT**
- to patch *existing* GCC passes:
  MELT provide extensions thru the plugins framework, which enable adding your new passes (but not really modifying existing passes, unless you replace them).
- to add *new front-ends* or *new back-ends* to GCC
  since it is impossible today (gcc 4.5) thru plugins
- for any GCC enhancement not doable with the plugin mechanism
  MELT uses extensively the plugin hooks

[10] You probably will need 2Gbytes of RAM and 3Gbytes of disk to compile MELT generated code

[11] The MELT infrastructure is itself a plugin, unless you use the MELT branch; but even the MELT branch is using plugin hooks.

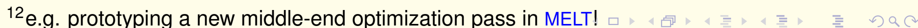
When and why use MELT

Assuming that you are able to code GCC plugins and learned a bit about MELT

1. to **experiment new ideas**[12] inside GCC
   MELT should provide you increased productivity, since it is more expressive than C programming language
2. to **develop specific GCC extensions**
   MELT enables development of **your** application-, domain-, corporation-, project-, **specific GCC extensions** (which are not economically doable in C plugins)

With MELT, you can take advantage of the power of GCC for many source code related activities (and use GCC for source-code related tasks outside of ordinary compilation).

[12] e.g. prototyping a new middle-end optimization pass in MELT!



availability of MELT

MELT is available (but evolving) today!

```
svn co \
svn://gcc.gnu.org/svn/gcc/branches/melt-branch gcc-melt
```

also look on **gcc-melt.org** for releases

1. as a **plugin** to **unchanged** `gcc-4.5`[13] or to the trunk
2. as a **branch** [executable program `gcc-melt`]
   code very close[14] to gcc trunk (future 4.6). The main differences are shorter program options e.g. `gcc-melt -fmelt-mode=`μ instead of `gcc -fplugin-arg-melt-mode=`μ

Of course MELT is free software ©FSF and **GPLv3** licensed.

Your MELT extensions are possible with the same conditions as GCC plugins. It is preferable to have free **GPLv3** extensions. See `http://www.gnu.org/licenses/gcc-exception.html` for details.

[13] Use the `contrib/build-melt-plugin.sh` script
[14] merged with trunk more than weekly

MELT implementation details

MELT branch follows closely the trunk (svn repository files =) :

- `gcc/common.opt`, `gcc/toplevel.c` : patched for `-fmelt-`α options
- `gcc/Makefile.in`: build and bootstrap[15] MELT
- `gcc/melt-runtime.[ch]`: the MELT runtime (GC, module loading, low-level operations with values)
- `gcc/melt-make.mk`, `gcc/melt-module.mk`: Makefiles for MELT and for MELT modules
- `gcc/melt-predef.ist`: list of predefined MELT objects
- `gcc/melt-run.proto.h`: template generating `melt-run.h` included by every MELT generated C files.
- `gcc/melt/warmelt-*.melt`: the "bootstrapped" MELT system and translator
- `gcc/melt/generated/warmelt-*0.c`: corresponding generated C files
- `gcc/melt/xtramelt-*.melt`: extra MELT files (e.g. MELT operations on `gimple` ..., simple MELT passes)

[15] "cold" `gcc/melt/generated/warmelt*0*.c` + `gcc/melt/warmelt*.melt` → `warmelt*.1*.c` + `gcc/melt/warmelt*.melt` → `warmelt*.2*.c` + `gcc/melt/warmelt*.melt` → `warmelt*.c`

Hints for building GCC MELT [branch]

- same advices as for GCC (in particular *build tree* ≠ *source tree*)
  See `http://gcc.gnu.org/install/`
- same dependencies as for GCC (trunk or 4.5)
- the *Parma Polyhedra Library* **PPL** (preferably 0.11) should be `configure`-d with `--enable-interfaces=c` at least[16]
- after updating the GCC MELT branch source from **svn** repository by running `./contrib/gcc_update` in the *source* tree, don't forget to `rm -f gcc/melt-runtime.o gcc/warmelt*.[co]` in the *build* tree!
- perhaps use **ccache** carefully from `http://ccache.samba.org/`
- parallel `make -j` useful for `cc1` but useless for `melt.encap`
  (since MELT is generating C files and compiling them just after)

[16] This is the issue if you get undefined symbols when linking `cc1` for symbols like `ppl_io_asprint_Polyhedron`

about my system Debian/Testing/AMD64 or Ubuntu/Maeverick/AMD64

shell run 1

```
echo $GCCMELTSOURCE $GCCMELTBUILD; gcc-melt -v |& grep 'gcc version'
```

⇒

```
/usr/src/Lang/basile-melt-gcc /usr/src/Lang/_Obj_Gcc_Melt
gcc version 4.6.0 20101019 (experimental) [melt-branch revision 165706] (GCC)
```

shell run 2

grep bash.*configure *GCCMELTBUILD/config.status*0

⇒

```
/usr/src/Lang/_Obj_Gcc_Melt/config.status:  set X '/bin/bash'
'/usr/src/Lang/basile-melt-gcc/configure'  '--program-suffix=-melt'
'--libdir=/usr/local/lib/gcc-melt' '--libexecdir=/usr/local/libexec/gcc-melt'
'--with-gxx-include-dir=/usr/local/lib/gcc-melt/include/c++/'
'--with-mpc-include=/usr/local/include' '--with-mpc-lib=/usr/local/lib'
'--enable-maintainer-mode' '--enable-checks=tree,gc' '--disable-bootstrap'
'--disable-multilib' '--enable-version-specific-runtime-libs' '--enable-plugin'
'CC=gcc' 'CFLAGS=-O -g' '--with-ppl-include-dir=/usr/local/include'
'--with-ppl-lib-dir=/usr/local/lib' '--enable-languages=c,c++,lto'
```

Hints for building MELT plugin for GCC 4.5

- for developing significant MELT extensions, the GCC MELT branch is preferable (in particular because `ENABLE_CHECKING` gives you more debug related features, but is usually disabled in *released* GCC compilers)
- it could be worthwhile to build your `gcc-4.5` with `--enable-checks` for ease of development of your MELT extensions
- running `gengtype` for plugins is very painful in GCC 4.5. Consider copying manually `contrib/gt-melt-runtime-plugin-4.5.h` to `gcc/gt-melt-runtime.h` in your plugin build tree.
- read `INSTALL/README-MELT-PLUGIN`
- read and run `contrib/build-melt-plugin.sh` accordingly

please report any bugs about MELT as plugin

Why use MELT for specific extensions?

MELT is mostly **useful for** *(application-, domain-, industry-, project-)* ***specific*** **GCC extensions**, e.g.

- particular warnings or checks, like:
  - warn when the result of `fopen` is not tested...
  - type variadic functions like `g_object_set` in Gtk
- specific optimizations, like `fprintf(stdout,...)` ⇒ `printf(...)`
- coding rule validation, like In C++, *"ensure base classes common to more than one derived class are virtual"* (HICPP 3.3.15). or *Every call to* `pthread_mutex_lock` *should be followed by a similar call to* `pthread_mutex_unlock` *in the* ***same*** *block.*
- source code processing (e.g. aspect oriented programming, retro-engineering, re-factoring tasks)

Notes:

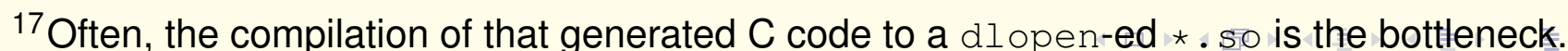
1. most such extensions are specific and probably don't belong inside GCC.
2. same arguments go for plugins coded in C; however, MELT is believed to **increase your productivity** while coding such extensions.

MELT extensions vs coding plugins in C

MELT(being based on the plugin machinery) permits the same extensions as GCC plugins coded in C.

- C is efficient at execution time, but difficult to use for custom middle-end processing (C is not an easy language to code compilers or static analyzers)
- specific extensions (to be coded in MELT) needed to be coded quickly
- MELT has many features tailored to processing of GCC internals
  1. automatic **memory management** (a powerful garbage collector)
  2. powerful **pattern matching**
  3. **high-level programming styles**: object-oriented, functional, applicative, reflexive abilities, dynamic typing, meta-programming...
  4. MELT is very **tightly related to GCC internals**
  5. MELT code is **translated to C code**[17] suited for GCC
- gluing an existing scripting language implementation (e.g. Ruby, Python, Ocaml) into GCC is not realistic (because GCC API is not stable, huge, and not well defined by C functions.)

[17] Often, the compilation of that generated C code to a `dlopen`-ed `*.so` is the bottleneck.



MELT garbage collector versus Ggc

	MELT GC	Ggc[18]
Design:	designed from start in parallel with the MELT language	added as a crude hack
Manage:	MELT values	stuff = GTY-ed structures
Based upon:	Ggc $\rightarrow$	system `malloc`
Time:	$O(\lambda)$ $\lambda =$ size of live values	$O(\sigma)$ $\sigma =$ total memory size
Type:	generational, copying	precise, mark & sweep
Roots:	**local variables** and static	only static GTY-ed data
Invocation:	implicitly, when needed	between passes only
Implementation:	runtime suited for code generator	quick and dirty hack [19]
Suited for:	short-lived temporary values	quasi-permanent data
Allocation:	very quick	a non-trivial function call
Usage:	in generated C code	in hand-written C

The MELT old generation is the Ggc heap, so MELT is compatible with Ggc[20]. A minor GC happens after each MELT pass.

[18] Ggc is the "garbage collector" inside GCC. `gcc/ggc*.[ch]` and `gcc/gengtype*`
[19] the `ggc` functions & `GTY` annotations preprocessed by `gengtype`
[20] but MELT is not compatible with Pch

MELT code suitable for its garbage collector

MELT GC requires that every MELT call frame is explicited (as a C `struct`) in the generated code, and containing every local thing (e.g. values and `GTY`-ed data). Typical C code looks almost like (in `gcc/melt-runtime.c`)

```
1  melt_ptr_t meltgc_new_gimple (meltobject_ptr_t discr_p, gimple g)
2  {
3    MELT_ENTERFRAME (2, NULL);
4  #define bgimplev  meltfram__.mcfr_varptr[0]
5  #define discrv  meltfram__.mcfr_varptr[1]
6  #define object_discrv ((meltobject_ptr_t)(discrv))
7    discrv = (void *) discr_p ? : MELT_PREDEF (DISCR_GIMPLE);
8    if (melt_magic_discr ((melt_ptr_t) discrv) != MELTOBMAG_OBJECT)
9      goto end;
10   if (object_discrv->object_magic != MELTOBMAG_GIMPLE) goto end;
11   bgimplev = meltgc_allocate (sizeof (struct meltgimple_st), 0);
12   ((struct meltgimple_st *) (bgimplev))->discr = discrv;
13   ((struct meltgimple_st *) (bgimplev))->val = g;
14 end:
15   MELT_EXITFRAME ();
16   return (melt_ptr_t) bgimplev;
17 }
```

Conventions expected by MELT garbage collector

- MELT call frames are declared as `struct`-ure `meltframe__`, cleared and linked to the previous (with `MELT_ENTERFRAME`);
- every C MELT value formal argument should be copied into that frame;
- this call frame should be unlinked with `MELT_EXITFRAME`;
- **every MELT value** should be a local field in its `meltframe__`;
- → The generated code cannot have `xv=f (g (yv), zv);` but should have a unique temporary `tmpv= g (yv); xv =f (tmpv, zv);`. This is easier to achieve in generated C code.
- the MELT GC can be triggered at every MELT allocation[21]
- updates inside touched MELT values should be signaled (write barrier `meltgc_touch`)

[21] When the allocation birth zone is full, a copying minor GC is triggered. Every live value is copied out of it, and the birth zone (of e.g. a megaword) can be `free`-d at once. Sometimes a full GC occurs by calling `ggc_collect` just after the minor GC. Minor GCs are forced before returning inside GCC code, e.g. at end of every GCC pass coded in MELT.

Gory details about MELT garbage collection

- the MELT GC handles only MELT values ; GCC stuff (`gimple`, `tree`, ...) is managed by Ggc
- "strongly" typed GC: MELT values are handled differently from GCC stuff
- explicit local frame allocation using `MELT_ENTERFRAME` and `MELT_EXITFRAME` macros
- local frame is `meltfram__` with local values acessed thru `#define meltfptr meltfram__.mcfr_varptr` etc.
- write barrier: updated values should go thru `meltgc_touch`.
- coding in hand-written C for MELT is somehow painful
- but almost all the C code is generated
- the only way to allocate MELT values is `meltgc_allocate`, which may call `melt_garbcoll` (which sometimes calls `ggc_collect`)
- MELT GC is tunable thru parameters `melt-minor-zone`, `melt-full-threshold` & `melt-full-period`

Terminology

- **plugin:** only `melt.so` as plugin to `gcc-4.5` built from `gcc/melt-runtime.[ch]` and loaded when `-fplugin=melt.so`
- **MELT runtime:** the functions from `gcc/melt-runtime.[ch]`[22]
- **MELT language:** our lispy domain specific language[23]
- **MELT file:** a ϕ`.melt` file in our lispy MELT language
- **source file:** the `*.c *.cc *.f90` ... files compiled by GCC
- **MELT generated file:** the ϕ`.c` file generated from ϕ`.melt` by the MELT translator
- **MELT module:** the ϕ`.so` shared object, dynamically loaded from the MELT runtime (calling conventions specific to MELT and unrelated to GCC plugins)
- **MELT mode:** usually, a word or identifier ω passed with `gcc-4.5 -fplugin=melt.so -fplugin-arg-melt-mode=`ω or `gcc-melt` **`-fmelt-mode=`**ω. No extra processing happens without a mode.
- **GCC stuff:** any internal (often `GTY`-ed) data inside `gcc-4.5` (or trunk), e.g. `long` or `gimple` or `edge` ...

[22] Runtime provided by the `melt.so` plugin for `gcc-4.5`, or included in `gcc-melt`
[23] A future infix form would be called `*.milt`

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Running MELT

Without any mode, [nothing more happens, so] running `gcc-melt -O -c foo.c` is the same as `gcc-trunk -O -c foo.c` or `gcc-4.5 -fplugin=melt.so -O -c foo.c`

The `gcc` compiler driver requires some source file. In some modes, it is useful to compile an `empty.c` file (simply to get `cc1` started):

- translate your `foo.melt` to module `foo.so`:

```
gcc-melt -fmelt-mode=translatetomodule \
         -fmelt-arg=foo.melt -c empty.c
```

- translate your `foo.melt` and run it immediately when compiling `bar.c`:

```
gcc-melt -fmelt-mode=runfile -fmelt-arg=foo.melt \
         -O -c bar.c
```

Notice that in both cases, the `cc1` started by `gcc-melt` is itself generating a C file and `fork`-ing its compilation[24] into a MELT module.

[24] Actually `cc1` is `pex_execute`-ing a `make` command using `melt-module.mk`!

Running MELT as plugin

With `melt.so` as plugin to GCC 4.5, the commands are:

- translate your `foo.melt` to module `foo.so`:

```
gcc-4.5 -fplugin=melt.so  \
        -fplugin-arg-melt-mode=translatetomodule \
        -fplugin-arg-melt-arg=foo.melt -c empty.c
```

- translate your `foo.melt` and run it immediately when compiling `bar.c`:

```
gcc-4.5 -fplugin=melt.so \
        -fplugin-arg-melt-mode=runfile \
        -fplugin-arg-melt-arg=foo.melt -O -c bar.c
```

In general, $\forall \alpha$

`-fplugin-arg-melt-`α for `gcc-4.5 -fplugin=melt.so`

$\equiv$ `-fmelt-`α for `gcc-melt`

Existing MELT modes

they don't fit all on the screen!

shell run

```
gcc-melt -fmelt-mode=help -c empty.c
```

⇒

```
 * help : MELT help about available modes.
 * justscan : install a pass scanning all the code
 * makedoc : generate .texi documentation from .melt source files;

 ARGLIST= input file, ...; OUTPUT= generated file
 * makegreen : enable a pass finding fprintf to stdout...
 * nop : a mode doing nothing.
 * rundebug : translate and run a .melt file for debug;

 ARGUMENT= input file;  [OUTPUT=generated C]
 * runfile : translate and run a .melt file.

 ARGUMENT= input file; [OUTPUT=generated C].
 * smallana : install a small analysis pass
 * translatedebug : translate a .melt file to .so module for debug;

 ARGUMENT= input file; OUTPUT= generated module *.so;

 generates also *.c and no MELT line number;

 Useful for running gdb on the module
```

MELT files, directories, paths

- MELT **builtin source directory** [25] for "MELT system" files `warmelt-*.melt` (the MELT infrastructure and translator) and `xtramelt-*.melt` (extra MELT passes and functions). Also contains the corresponding translation `warmelt-*.c`.
- MELT **builtin module directory** [26] for the "MELT system", contains the executable modules `warmelt-*.so` and `xtramelt-*.so` and their default list `melt-default-modules.modlis`
- colon separated MELT **source path** of directories, used to find MELT source files `*.melt` & `*.c`, from program argument `-fmelt-source-path` or environment variable `GCCMELT_SOURCE_PATH`.
- MELT **module path** of directories, used to find MELT module files `*.so` (or their `*.modlis` list), from `-fmelt-module-path` or `GCCMELT_MODULE_PATH`
- MELT colon separated **initial module list** `-fmelt-init` is a list of modules or `@` module lists. Defaults to `@@` for `@melt-default-modules`

[25] e.g. `/usr/local/libexec/gcc/gcc-melt/x86_64-unknown-linux-gnu/4.6.0/melt-source` which is always seeked

[26] e.g. `/usr/local/libexec/gcc/gcc-melt/x86_64-unknown-linux-gnu/4.6.0/melt-module`

other significant MELT program options

- a single argument `-fmelt-arg=`α (e.g. a MELT input file to translate);
- a secondary argument `-fmelt-secondarg=`α;
- an output argument `-fmelt-output=`ω (e.g. a MELT generated C file);
- an option argument `-fmelt-option=`α;
- a temporary directory `-fmelt-tempdir=`δ;
- a comma separated argument list `-fmelt-arglist=`α_1`,`α_2;
- the makefile to build MELT modules from MELT generated C files `-fmelt-module-makefile`[27]
- the make command to built them `-fmelt-module-make-command`

[27] the builtin default is `/usr/local/libexec/gcc-melt/gcc/x86_64-unknown-linux-gnu/4.6.0/melt-module.mk`

MELT lispy dialect

Why a Lispy syntax? Because I am lazy[28], and because of Emacs-Lisp and Guile!

As usual:

- Lisp $\equiv$ **L**ots of **I**nsipid **S**tupid **P**arenthesis
- Parenthesis are **very** important: $\phi \neq$ **(** ϕ **)** and always matched
- MELT syntactic constructs are always prefix[29] like **(** Ω α_1 ... α_n **)** where Ω is the operator and the α_i are the $n \geq 0$ operands or arguments.

[28] no time to create a sexy syntax and an Emacs mode for it

[29] Except syntactic sugar like **'** or **?** etc.

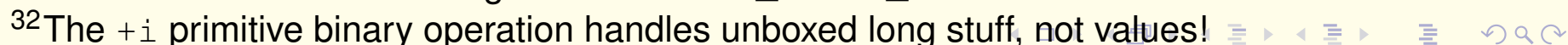
MELT vs other lisps

- MELT is **lexically scoped** (à la Scheme) with a single namespace.
- MELT can handle non-value data called **stuff**
- **nil**, noted `()`, **is** the only **false** value[30]
- several major syntactic constructs are noted nearly like in other Lisps: **`let` `if` `lambda` `cond` `defun` `definstance` `setq`** ...
- symbols (e.g `if` or `foo`) are objects of `class_symbol`
- keywords (e.g `:else` or `:gimple`) are objects of `class_keyword`
- source s-expressions are parsed as instances of `class_sexpr` and know their location
- lists are not just simply linked pairs
- no familiar operations : there is no `car`[31], `cons`, or `+`[32] in MELT
- **`'2` $\neq$ 2**, because **`'2` is a** [boxed long] **value** but **2 is** some **`:long` stuff**

[30] Every non-nil value is true. But the stuff `0` is false!

[31] The first element of a list is gotten with `list_first_element`

[32] The `+i` primitive binary operation handles unboxed long stuff, not values!



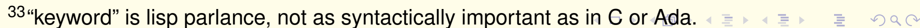
main MELT lexical conventions

- identifiers or **symbols** are case insensitive, so `let` is the same as `LeT` symbols may contain a few special characters, e.g. `<i` or `+i`
- "**keywords**" start with a colon like `:long` or `:else`[33]
- comments start with a semi-colon `;` up to end of line
- strings are nearly like in C (so `"a\nb"` has three characters...).
- **macro-strings** (for C code chunks with MELT "hole" variables) with `#{ ... }#` so

```
#{/*$P*/printf("a=%ld\n", $A);}#
≡
("/*"  p   "*/printf(\"a=%ld\\n\", "  a  ");")
```

- `'`ϵ is **syntactic sugar** for `(quote` ϵ`)`, e.g. `'"ab"` ≡ `(quote "ab")` and `'if` ≡ `(quote if)`
- `?`ϵ is **syntactic sugar** for `(question` ϵ`)`, so `?x` ≡ `(question if)`

[33] "keyword" is lisp parlance, not as syntactically important as in C or Ada.



Hello world in MELT

```
;;;;;;; file hello.melt                     -*- lisp -*-
;;; a comment for the generated C code
(comment "hello world is public domain")
;;; a code chunk containing C
(code_chunk say-hello-chunk
           #{printf("hello from MELT %s:%d\n",
                    __FILE__, __LINE__);}#)
;;;;;;; eof hello.melt
```

the **comment** is translated into a C comment. The **code_chunk** adds some C code chunk in the generated C file. MELT source line numbers are preserved in the generated C file thru `#line` directives.

shell run 4

```
gcc-melt -fmelt-mode=runfile -fmelt-arg=hello.melt -c empty.c
```

⇒

```
hello from MELT hello.melt:8
```

building the `hello` module and running it

shell run 5

```
gcc-melt -fmelt-mode=translatetomodule -fmelt-arg=hello.melt -c empty.c
```

⇒

shell run 6

```
ls -lt hello.*
```

⇒

```
-rw-r--r-- 1 meltuser meltuser  10992 Oct 26 03:09 hello.c
-rwxr-xr-x 1 meltuser meltuser 135408 Oct 26 03:09 hello.so
-rw-r--r-- 1 meltuser meltuser  10989 Oct 26 03:09 hello.c%
-rw-r--r-- 1 meltuser meltuser    286 Oct 22 16:31 hello.melt
```

shell run 7

```
gcc-melt -fmelt-init=@@:hello -c empty.c
```

⇒

Nothing happenned, since there is no mode.

shell run 8

```
gcc-melt -fmelt-module-path=. -fmelt-init=@@:hello -fmelt-mode=nop -c empt
```

⇒

```
hello from MELT hello.melt:8
```

MELT files and modules

Very Scheme inspired:

- a MELT source file ϕ`.melt` contains a sequence of **expressions** [34] and is compiled into a melt module ϕ`.so` (with a big initialization function for the evaluation of each expression).
- the melt runtime `dlopen`-s the ϕ`.so` module
- modules are loaded in sequence, and the MELT system has an initial sequence[35] (containing the translator and initial environments). User modules are loaded after these.
- a module consumes an environment and produces a new one, as a translated side effect of evaluating the expressions in ϕ`.melt`. Only **exported bindings** are visible outside of the module.

In practical terms, a MELT source file contains defining and/or side-effecting expressions. It can install new modes and new GCC passes etc. Translating ϕ`.melt` to ϕ`.c` is much faster than compiling the generated ϕ`.c` to ϕ`.so`.

[34] It is also possible to compile a sequence of expressions from the MELT heap into a module!

[35] the modules `warmelt-*.so` and `xtramelt-*.so` listed in `melt-default-modules` abreviated by `@@`

main MELT syntactic constructs

expressions where $n \geq 0$ and $p \geq 0$

application	$(\phi\ \alpha_1\ \ldots\ \alpha_n)$	apply function (or primitive) ϕ to arguments α_i
assignment	(**setq** $\nu\ \epsilon$)	set local variable ν to ϵ
message send	$(\sigma\ \rho\ \alpha_1\ \ldots\ \alpha_n)$	send selector σ to reciever ρ with arguments α_i
let expression	(**let** $(\beta_1 \ldots \beta_n)\ \epsilon_1 \ldots \epsilon_p\ \epsilon'$)	with local **sequential**[36] bindings β_i evaluate side-effecting sub-expressions ϵ_j and give result of ϵ'
sequence	(**progn** $\epsilon_1 \ldots \epsilon_n\ \epsilon'$)	evaluate ϵ_i (for their side effects) and at last ϵ', giving its result (like operator `,` in C)
abstraction[37]	(**lambda** $\phi\ \epsilon_1 \ldots \epsilon_n\ \epsilon'$)	anonymous function with formals ϕ and side-effecting expressions ϵ_i, return result of ϵ'
pattern matching	(**match** $\epsilon\ \chi_1\ \ldots\ \chi_n$)	match result of ϵ against match clauses χ_i, giving result of last expression of matched clause.

[36] So the `let` of MELT is like the `let*` of Scheme!

[37] abstractions are constructive expressions and may appear in letrec bindings

A cleared thing[38] (represented by all zero bits) is nil, or the `long` 0 stuff, or the null `gimple` or `tree` ... stuff. It is false.

conditional expressions where $n \geq 0$ and $p \geq 0$

test	`(if` τ θ ϵ`)`	if τ then θ else ϵ (like `?:` in C)
conditional	`(cond` κ_1 ... κ_n`)`	evaluate conditions κ_i until one is satisfied
conjonction	`(and` κ_1 ... κ_n κ'`)`	if κ_1 and then κ_2 ... and then κ_n is "true" (non nil or non zero) then κ' else the cleared thing of same type
disjunction	`(or` δ_1 ... δ_n`)`	the first of the δ_i which is "true" (non nil, or zero, ...)

In a `cond` conditional expression, every condition κ_i -except perhaps the last- is like `(`γ_i $\epsilon_{i,1}$ ... ϵ_{i,p_i} ϵ'`)` with $p_i \geq 0$. The first such condition for which γ_i is "true" gets its sub-expressions $\epsilon_{i,j}$ evaluated sequentially for their side-effects and gives its ϵ'. The last condition can be `(:else` ϵ_1 ... ϵ_n ϵ'`)`, is triggered if all previous conditions failed, and (with the sub-expressions ϵ_i evaluated sequentially for their side-effects) gives its ϵ'

[38] Every local thing (value, stuff ...) is cleared at start of its containing MELT function.

more expressions

loop	`(forever` λ α_1 ... α_n`)`	loop indefinitely on the α_i which may exit
exit	`(exit` λ ϵ_1 ... ϵ_n ϵ'`)`	exit enclosing loop λ after side-effects of ϵ_i and result of ϵ'
return	`(return` ϵ ϵ_1 ... ϵ_n`)`	return ϵ as the main result, and the ϵ_i as secondary results
multiple call	`(multicall` ϕ κ $\epsilon_1 ... \epsilon_n$ ϵ'`)`	locally bind formals ϕ to main and secondary result[s] of application or send κ and evaluate the ϵ_i for side-effects and ϵ' for result
recursive let	`(letrec` $(\beta_1 ... \beta_n)$ $\epsilon_1 ... \epsilon_p$`)`	with co-recursive *constructive* bindings β_i evaluate sub-expressions ϵ_j
field access	`(get_field :`Φ ϵ`)`	if ϵ gives an appropriate object[39] retrieves its field Φ, otherwise nil
unsafe field access	`(unsafe_get_field :`Φ ϵ`)`	unsafe[40] access without check like above
object update	`(put_fields` ϵ `:`Φ_1 ϵ_1 ... `:`Φ_n ϵ_n`)`	safely update [41] (if appropriate) in object given by ϵ each field Φ_i by value of ϵ_i

[39] i.e. if the value ω of ϵ is an object which is a direct or indirect instance of the class defining field Φ.

[40] Only for MELT gurus, since it may crash!

[41] i.e. update object ω only if the value ω of ϵ is an object which is a direct or indirect instance of the class defining each field Φ_i

constructive expressions

list	`(list` α_1 ... α_n`)`	make a list of n values α_i
tuple	`(tuple` α_1 ... α_n`)`	make a tuple of n values α_i
instance	`(instance` κ `:`Φ_1 ϵ_1 ... `:`Φ_n ϵ_n`)`	make an instance of class κ and n fields Φ_i set to value ϵ_i

Abstractions (**lambda** expressions) are also constructive.

Constructive expressions may be recursively bound in **letrec**:

```
1 (letrec (
2       (a (list b c))
3       (b (tuple a b))
4       (c (lambda (x y) (if (== x a) b y)))
5       (d (instance class_container :container_value a))
6   )
7   (c d bar))
```

Note: contrarily to Scheme, **MELT has no tail recursive calls**.

Every [recursive] MELT call grows the stack (because it is translated to a C call).

expressions about names

	expressions defining names	
for functions	(**defun** ν ϕ ϵ_1 ... ϵ_n ϵ')	define function ν with formal arguments ϕ and body ϵ_1 ... ϵ_n ϵ'
for primitives	(**defprimitive** ν ϕ :θ η)	define primitive ν with formal arguments *phi*, result c-type θ by macro-string expansion η
for c-iterators	(**defciterator** ν Φ σ Ψ η η')	define c-iterator ν with input formals Φ, state symbol σ, local formals Ψ, start expansion η, end expansion η'
for c-matchers	(**defcmatcher** ν Φ Ψ σ η η')	define c-matcher ν with input formals Φ *[the matched thing, then other inputs]*, output formals Ψ, state symbol σ, test expansion η, fill expansion η'
for fun-matchers	(**defunmatcher** ν Φ Ψ ϵ)	define funmatcher ν with input formals Φ, output formals Ψ, with function ϵ
	expressions exporting names	
of values	(**export_value** ν_1 ...)	export the names ν_i as bindings of value (e.g. of functions, objects, matcher)
of macros	(**export_macro** ν ϵ)	export name ν as a binding of a macro (expanded by the ϵ function)
of classes	(**export_class** ν_1 ...)	export every class name ν and all their fields (as value bindings)
as synonym	(**export_synonym** ν ν')	export the new name ν as a synonym of the existing name ν'

miscellanous expressions

For all:

expressions for debugging

debug message	`(debug_msg` ϵ μ`)`	debug printing message μ & value ϵ
assert check	`(assert_msg` μ τ`)`	nice "halt" showing message μ when asserted test τ is false
warning	`(compile_warning` μ ϵ`)`	like `#warning` in GCC C: emit warning μ at MELT translation time and gives ϵ

meta-conditionals

Cpp test	`(cppif` σ ϵ ϵ'`)`	conditional on a preprocessor symbol: emitted C code is `#if` σ code for ϵ `#else` code for ϵ' `#endif`
Version test	`(gccif` β ϵ_1 ...`)`	the ϵ_i are translated only if the GCC translating them has version prefix string β

For gurus:

introspective expressions

Parent environment	`(parent_module_environment)`	gives the previous module environment
Current environment	`(current_module_environment_container)`	gives the container of the current module's environment

MELT values [and stuff] from inside

An example: **boxed** gimple (values containing a raw `gimple` pointer) from `melt-runtime.h`

```
struct GTY (()) meltgimple_st {
  meltobject_ptr_t discr;
  gimple val;
};
```

Every MELT value has a **discriminant**. Such a discriminant is a non-null MELT **object** (not all values are objects).
MELT values are **first-class**. Non-value stuff (e.g. raw `gimple` or `long`) is second-class.

Things	=	***Values***	∪	***Stuff***
any data relevant to MELT		first class, with discriminant		second class, like `gimple` or `long`

stuff handled by MELT

Potentially, any data inside GCC. In practice

- `long` raw integers
- `cstring`, i.e. constant array of chars like `"mutable"` - the `const char []` data! These are not heap-allocated!
- Major GCC data types like `gimple`, `gimple_seq`, `tree`, `basic_block`, `edge`, `loop`, `rtx`, `rtvec` & `bitmap`
- *PPL* data like `ppl_coefficient` etc.
- `void` (like in C, for absence of result)
- MELT `value`-s are not really stuff...

Any `GTY`-ed type could be handled as some stuff.[42]
Stuff are second-class[43] in MELT. Handling first-class values is simpler.

[42] Adding extra `GTY`-ed data types requires additional code in the MELT runtime.
[43] They can only be secondary arguments or results.

MELT simple values

Most stuff can be boxed as a simple value, .e.g

- boxed `gimple`
- boxed `tree`
- boxed `long`
- etc.
- the nil value

Strings are immutable (heap-allocated) MELT values. Several discriminants[44] are possible e.g. `discr_verbatim_string` and `discr_string`.
String buffers contain a growable sequence of characters.

[44] One could also have several kinds or colors of boxed `gimple` by making several discriminants for them.

MELT aggregate values

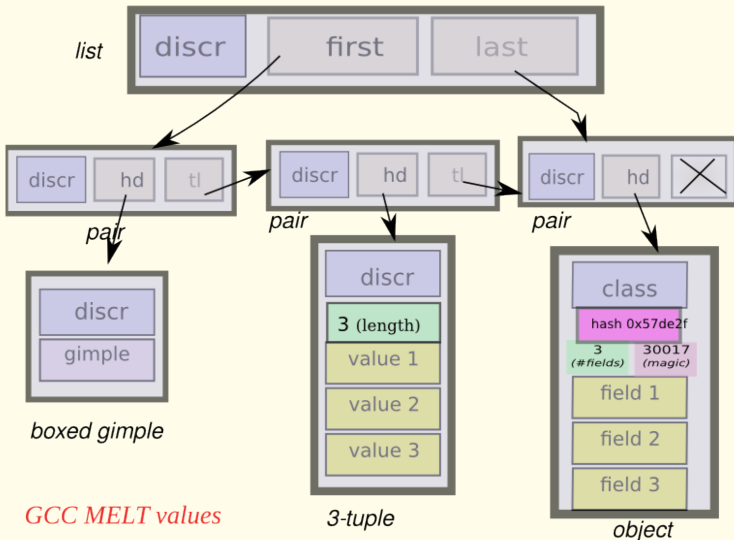
1. **tuples**, i.e. fixed sequence of values
2. pairs (head is any value, tail is a pair or nil)
3. **lists** (it knows its first and last pair)[45]
4. MELT **objects** (described below)
5. **closures** (a MELT function with values)
6. associative **hash-maps** associating keys[46] to non-nil values:
   - string maps (= dictionnary); keys are string values.
   - object maps; keys are MELT objects
   - `gimple`, `tree`, `edge` ... maps; key are non nil stuff (all of the same C type).

Hash-maps are quite important, it is the only way to **associate MELT values to major GCC data types** like `gimple` or `basic_block`

[45] So MELT lists are **not** like in Scheme or Lisp!

[46] But we don't have maps associating non-object values -like closures, boxed `edge`-s, or tuples- to other values.

aggregate values (figure)



MELT objects representation

```
1  typedef struct meltobject_st* meltobject_ptr_t;
2  struct GTY ((variable_size)) meltobject_st {
3    /* for objects, the discriminant is their class */
4    meltobject_ptr_t obj_class;
5    unsigned obj_hash;         /* hash code of the object */
6    unsigned short obj_num;
7  /* discriminate the melt_un containing it as discr */
8  #define object_magic obj_num
9    unsigned short obj_len;
10   melt_ptr_t GTY ((length ("%h.obj_len")))
11       obj_vartab[FLEXIBLE_DIM];
12 };
```

The `obj_num` (≡ `object_magic`) field is set at most once to a non-zero short.

The `object_magic` field of discriminants (starting every MELT value) is describing in the `union melt_un` the `GTY`-ed field.

The MELT values in `melt-runtime.h`

```
1  typedef union melt_un* melt_ptr_t;
2  union GTY ((desc ("%0.u_discr->object_magic"))) melt_un {
3    meltobject_ptr_t GTY ((skip)) u_discr;
4    struct meltmultiple_st
5      GTY ((tag ("MELTOBMAG_MULTIPLE"))) u_multiple;
6    struct meltobject_st
7      GTY ((tag ("MELTOBMAG_OBJECT"))) u_object;
8    struct meltlist_st
9      GTY ((tag ("MELTOBMAG_LIST"))) u_list;
10   struct meltclosure_st
11     GTY ((tag ("MELTOBMAG_CLOSURE"))) u_closure;
12   struct meltgimple_st
13     GTY ((tag ("MELTOBMAG_GIMPLE"))) u_gimple;
14   struct meltmapobjects_st
15     GTY ((tag ("MELTOBMAG_MAPOBJECTS"))) u_mapobjects;
16   struct meltmapgimples_st
17     GTY ((tag ("MELTOBMAG_MAPGIMPLES"))) u_mapgimples;
18 //  etc ...
19 };
```

MELT classes and object creation

e.g. MELT mode for GCC pass

Dynamic object creation with **`instance`** (from `gcc/melt/xtramelt-ana-simple.melt`)

```
1  (defun makegreen_docmd (cmd moduldata) ;; unused formals
2    (let ( (greenpass
3              (instance class_gcc_gimple_pass
4                        :named_name '"melt_greenpass"
5                        :gccpass_gate makegreenpass_gate
6                        :gccpass_exec makegreenpass_exec
7                        :gccpass_data
8                            (make_maptree discr_map_trees 100)
9                        :gccpass_properties_required ()
10                 )
11         ) )
12  ;;; register our pass after the "phiopt" pass
13   (install_melt_gcc_pass greenpass "after" "phiopt" 0)
14 ;; return non-nil, e.g. our greenpass, to accept the mode
15   greenpass)))
```

In the above **`makegreen_docmd`** function -called from the `makegreen` MELT mode-, an instance of **`class_gcc_gimple_pass`** is created and registered as a GCC pass

static creation with `definstance` which defines a MELT variable statically bound to an instance:
definition and installation of a MELT mode

```
1 (definstance makegreen_mode
2   class_melt_mode
3   :named_name '"makegreen"
4   :meltmode_help
5      '"enable a pass finding fprintf to stdout..."
6   :meltmode_fun makegreen_docmd
7 )
8 (install_melt_mode makegreen_mode)
```

defining a MELT class

MELT classes are defined with **defclass**, by giving the super-class and the sequence of fields (instance variables).

```
1  ;; class describing MELT options
2  (defclass class_option_descriptor
3    :doc #{A class describing MELT options for -fmelt-option=}#
4    :super class_root
5    :fields (optdesc_name
6             optdesc_fun
7             optdesc_help)
8  )
```

There is a tree of classes. The topmost class (without any proper fields) is **class_root**. Conventionally, the class name starts with `class_`. Often, the field names share a common prefix.

Discriminants, classes and fields are reified : they are objects (of class **class_discriminant**, **class_class**, **class_field** respectively).

globally unique field names

The field names should be **globally** unique. This enables the safe `get_field` contruct, which tests that the accessed value is an object of the right class:

```
(get_field :container_value cont)
```

$\equiv$

```
1  (if (is_a cont class_container)
2      (unsafe_get_field :container_value cont)
3    ())
```

The `is_a` primitive tests that `cont` is an object, and is an instance of `class_container` or a sub-class. The discriminant of a value (e.g. the class of an instance) can be accessed with the `discrim` primitive. The discriminant of nil is conventionally `discr_null_reciever`. The subclassing relation is tested with `subclass_of` or `subclass_or_eq` primitives.

selector, methods and message sending

Selectors are “method names”. They are defined with **defselector**, similar to **definstance**.

```
;; selector for debugging output
(defselector dbg_output class_selector
  :formals (recv dbginfo :long depth)
  )
```

Once a selector is defined, every use of it as operator is a message send. The optional **:formals** given in a selector enable checking the signature of message sends.
Almost always, the class of a selector is **class_selector**[47].

Selectors exist independently of the discriminants (or classes) understanding them. Sending a message with a selector σ to a recieving value v whose discriminant δ don't know about σ is a no-op and gives nil.

[47] But it could be a sub-class of `class_selector`.

message sending and method installation

The sending of a message is $(\sigma \ \rho \ \alpha_1 \ \ldots \ \alpha_n)$ syntactically like an application[48], it has a selector σ, a recieving value ρ and secondary arguments α_i:

```
(dbg_output curval dbgi (+i depth 1))
```

Sending a message in MELT is more similar to Smalltalk sends than to methods calls in C++ or Java.

A method is just a function installed[49] with `install_method`. There is no special name (unlike `this` in C++) for the formal reciever.

```
;; null debug output
(defun dbgout_null_method (self dbgi :long depth)
  (let (  (out  (unsafe_get_field :dbgi_out dbgi))  )
    (add2out_strconst out "()")))
(install_method discr_null_receiver dbg_output
                dbgout_null_method)
```

[48] However, the selector in a message send is always a constant selector name. In contrast, in function applications, the applied function can be computed with a complex expression.

[49] Methods can be installed and removed dynamically at any time, independently of their discriminants and selectors.

message sending machinery

Every discriminant (i.e. class) has a method dictionnary, and a super-discriminant (i.e. the super-class of a class). To send a message with selector σ to reciever[50] ρ and extra arguments α_i of discriminant δ

1. look in the method dictionnary[51] of δ for a closure associated to σ
2. if a closure κ is found, use it as the method function and apply it (i.e. κ) to ρ and the α_i ...
3. otherwise, look in the super-discriminant δ' (e.g. super-class) of δ, and repeat by replacing δ with δ'.

The topmost discriminant is **`discr_any_reciever`**. It is the ultimate super-discriminant of every other discriminant or class.
Message sending is a bit slower than function application.

[50] Messages can be sent to any MELT value, even nil, closures, boxed gimples, maps...

[51] The field **`:disc_methodict`** in discriminants is a object hash map whose keys are selectors, associated to method closures.

MELT ctype - annotations for types of stuff

In formal argument lists, keywords like `:long` indicate the ctype of next formals, so the formal argument list `(x y :long n p :value z)` means : formals `x y` are values, `n p` are long stuff, then `z` is value.
Likewise, **`let`** binds sequentially[52] local variables

```
1 (let ( (:long n 0)
2          (:gimple g (gimple_content gb))
3        )
4        (f a n g))
```

Each stuff type has its ctype keyword, like `:gimple :gimple_seq :basic_block :long :cstring` etc.

[52] So MELT's `let` is like `let*` in Scheme!

MELT closures = functional values

A MELT function can take both values and stuff as arguments. First argument (if any) should be a value[53]. A function application[54] returns a value[55]. Only values can be closed.
Closures can be passed as arguments. Named functions are defined with **defun** (as in Emacs Lisp)

```
1 ;; apply f to each boxed gimple in a gimple seq gseq
2 (defun do_each_gimpleseq (f :gimple_seq gseq)
3   (each_in_gimpleseq
4    (gseq) (:gimple g)
5    (let ( (gplval (make_gimple discr_gimple g)) )
6      (f gplval)))
7 )
```

[53] It is the reciever in methods
[54] And hence message sendings
[55] Secondary results can be stuff.

application mechanism

- preferably, formals arguments and actual parameters should be similar (in number, in ctype). First formal and primary parameter should be a **`:value`**.
- no variable arity MELT functions exist.
- (in C code) secondary arguments (and secondary results if any) are passed thru arrays of `union meltparam_un` described by a constant string (produced by the MELT translator).
- if a formal argument mismatch its actual parameter, it is cleared with the rest of the formals
- primary result is a **`:value`**
- secondary actual results are handled similarily.

⇒ mismatched arguments or results are cleared.

Applying a non-closure value gives nil.

connecting the GCC API to MELT

Several linguistic devices exist:

- **`code_chunk`** to add C code inside MELT code (like `asm` adds assembly code inside C code).
- **`defprimitive`** to define primitive operations (by a translation “template” to C).
- **`defciterator`** to define iterative constructs
- **`defcmatcher`** to define pattern-matching constructs

Each take advantage of **macro-strings** (mixing strings for C code fragments with MELT symbols for “holes”).

C code in MELT with **code_chunk**-s

Useful to include unique C code. For example (with **modnamestr** bound to a string value)

```
(code_chunk
 checkerrorsaftercompilation
 #{ /*$checkerrorsaftercompilation*/
 if (melt_error_counter>0)
   melt_fatal_error ("MELT translation of %s halted: got %ld MELT errors",
      melt_string_str($modnamstr),
      melt_error_counter);
 }#)
```

Becomes translated to

```
/*CHECKERRORSAFTERCOMPILATION__1*/
if (melt_error_counter>0)
   melt_fatal_error ("MELT translation of %s halted: got %ld MELT errors",
     melt_string_str(/*_.MODNAMSTR__V3*/ meltfptr[2]),
                        melt_error_counter);
```

Notice the **substitution** of **$**-names: the **state symbol** **checkerrorsaftercompilation** with the unique `CHECKERRORSAFTERCOMPILATION__1` and **modnamstr** with `/*_.MODNAMSTR__V3*/ meltfptr[2]`

primitives with their C “template”

```
(defprimitive basicblock_nb_succ (:basic_block bb)
  :long
  #{(($BB)?EDGE_COUNT($BB->succs):0)}#)
```

The ctype of primitive application actual parameters is checked[56].

A primitive is translated into a C block or instruction if its resulting ctype is `:void`.

Otherwise, it is translated into a C expression.

When defining your primitives, make them safer by checking for null pointers!

[56] MELT gives an error at translation time if `basicblock_nb_succ` is given a thing which is not a `:basic_block`, (like a value or a long stuff).

defining iterative constructs with **defciterator**

The **each_in_gimpleseq** iterates for every gimple `g` inside a `gimple_seq` *gseq*:

```
;;;; iterate on a gimpleseq
(defciterator each_in_gimpleseq
  (:gimple_seq gseq)                          ;start formals
  eachgimplseq                                 ;state symbol
  (:gimple g)                                 ;local formals
  ;;; before expansion
  #{
   gimple_stmt_iterator gsi_$eachgimplseq;
   if ($gseq)
     for (gsi_$eachgimplseq = gsi_start ($gseq);
          !gsi_end_p (gsi_$eachgimplseq);
          gsi_next (&gsi_$eachgimplseq)) {
    $g  = gsi_stmt (gsi_$eachgimplseq);
  }#
  ;;; after expansion
  #{ /*end $eachgimplseq*/ } }# )
```

Translation (partly) in C

```
 /*citerblock EACH_IN_GIMPLESEQ*/ {
   gimple_stmt_iterator gsi_cit1__EACHGIMPLSEQ;
   if (/*_?*/ meltfram__.loc_GIMPLE_SEQ__o0)
     for (gsi_cit1__EACHGIMPLSEQ = gsi_start (/*_?*/ meltfram__.loc_GIMPLE_SEQ__
  !gsi_end_p (gsi_cit1__EACHGIMPLSEQ);
  gsi_next (&gsi_cit1__EACHGIMPLSEQ)) {
    /*_?*/ meltfram__.loc_GIMPLE__o1  = gsi_stmt (gsi_cit1__EACHGIMPLSEQ);
  MELT_LOCATION("xtramelt-ana-base.melt:2502:/ quasiblock");
#ifndef MELTGCC_NOLINENUMBERING
#line 2502 ".../xtramelt-ana-base.melt"
#endif /*MELTGCC_NOLINENUMBERING*/
  /*_.GPLVAL__V4*/ meltfptr[3] =
   (meltgc_new_gimple((meltobject_ptr_t)((/*!DISCR_GIMPLE*/ meltfrout->tabval[0]
  MELT_LOCATION("xtramelt-ana-base.melt:2503:/ apply");
  /*apply*/{
   /*_.F__V5*/ meltfptr[4] =  melt_apply ((meltclosure_ptr_t)(/*_.F__V2*/ meltfp
   };
  /*_.LET___V3*/ meltfptr[2] = /*_.F__V5*/ meltfptr[4];;
  MELT_LOCATION("xtramelt-ana-base.melt:2502:/ clear");
  /*clear*/ /*_.GPLVAL__V4*/ meltfptr[3] = 0 ;
  /*clear*/ /*_.F__V5*/ meltfptr[4] = 0 ;
  }
  MELT_LOCATION("xtramelt-ana-base.melt:2500:/ clear");
  /*clear*/ /*_?*/ meltfram__.loc_GIMPLE__o1 = 0 ;
  /*clear*/ /*_.LET___V3*/ meltfptr[2] = 0 ;}
```

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Patterns in MELT

- patterns are major nested syntactic constructs (like expressions are) in MELT.
- patterns appear in the `match` expression, with the **?** notation.
- patterns are a **destructuring mechanism**. They consume some thing (the matched data) μ, and extract several data-s from it (transmitted to sub-patterns).
- a pattern may **match** or **fail**.
- pattern variables are instanciated by the matching.
- a pattern matching involves a test (of the matched data, does it match?) and then a fill (of the transmitted data to sub-patterns)
- MELT patterns can be non-linear: the same pattern variable can appear more than once.

Similarity of patterns in the unix world: `sed` **regexpr**-s (or in Posix regular expressions in the `regexec` function): Regexpr-s consume strings, and extra matched substrings (thru `regmatch_t` in Posix `regexec`).
MELT patterns inspired by Ocaml's patterns mostly (and also Wadler's views, bananas, etc.).

an example of pattern use

```
1  (defun makegreen_transform (grdata :tree decl :basic_block bb)
2    (debug_msg grdata "makegreen_transform start grdata")
3    (debugbasicblock "makegreen_transform bb" bb)
4    (eachgimple_in_basicblock
5     (bb)    (:gimple g)
6     (match g
7            (?(gimple_assign_cast  ?lhs   ?rhs)
8              (debugtree "makegreen_transform assign cast lhs" lhs)
9              ;; etc
10           )
11           (?(gimple_assign_single
12              ?lhs ?(and ?rhs
13                         ?(tree_var_decl
14                           ?_ ?(cstring_same "stdout") ?_)))
15             (debugtree "makegreen_transform assign stdout lhs" lhs)
16             ;; etc
17           )
18           (?_
19             (debuggimple "makegreen_transform unmatched g" g)
20            ))))
```

`match` expressions

syntax

Syntax: `(match` ϵ χ_1 ... χ_n`)` where ϵ is the matched sub-expression and the χ_i are **match clauses**

Each match clause χ_i starts with a pattern π_i followed by one or more sub-expressions: $\chi_i \equiv (\pi_i \;\; \epsilon_{i,1} \;\; \ldots \;\; \epsilon_{i,n_i} \;\; \epsilon'_i)$

Patterns (usually starting with **?** - a question mark) may in particular be

- constants,
- **pattern variables** like `?x` or **jokers** like **`?_`**
- composite patterns with matchers, e.g. `?(gimple_assign_cast ?lhs ?rhs)`
- patterns made with “patmacros” like

```
?(and ?(gimple_cond_less ?lhs ?rhs)
      ?(gimple_cond_with_edges ?iftrue ?iffalse))
```

- etc ...

`match` expressions

informal semantics

First, the matched ϵ is evaluated to some matched thing μ (a value or a stuff).

The matched thing μ is matched with each pattern π_1 ... π_n in turn. When a matching pattern π_i is found, its pattern variables bound by the match are visible in the clause[57], and the sub-expressions $\epsilon_{i,1}$ ... ϵ_{i,n_i} are evaluated for their side effects and the last sub-expression ϵ'_i gives the result of the entire match.

Usually the sub-expressions in a match clause contains the pattern variables.

If no clause matches, the entire **`match`** expression gives a cleared result (nil value, 0 long stuff, `(gimple)0` stuff, ...).

The resulting ctype of the **`match`** expression is the common ctype of the ϵ'_i (or else **`:void`**)

[57] E.g. if `?x` appears inside π_2 and $\epsilon'_2 \equiv \mathtt{x}$, the result of the entire match expression is the thing matching `?x` when μ matches π_2

Pattern syntax

- expressions ϵ (e.g. constant literals) are (degenerated) patterns. They match the matched data μ iff $\epsilon == \mu$ (for the C sense of ==).
- The **joker** noted **?_** matches every thing and never fails.
- a pattern variable **?**ν matches μ if it was unset (by a previous [sub-]matching of the same **?**ν). In addition, it is then set to μ. If the pattern variable was previously set, it is tested for identity with == in the C sense.
- most patterns are **matcher** patterns `?(`$m\ \epsilon_1\ \ldots\ \epsilon_n\ \pi_1\ \ldots\ \pi_p$`)` where the $n \geq 0$ expressions ϵ_i are input parameters to the matcher m and the π_j sub-patterns are passed extracted data.
- instance patterns are `?(`**`instance`** κ **:**Φ_1 π_1 ... **:**Φ_n π_n`)`; matched μ is an object of [a sub-] class κ whose field Φ_i matches sub-pattern π_i.
- conjunctive patterns are `?(`**`and`** $\pi_1\ \ldots\ \pi_n$`)` and they match μ iff every π_i in sequence matches μ
- disjunctive patterns are `?(`**`or`** $\pi_1\ \ldots\ \pi_n$`)` and they match μ if one of the π_i matches μ

defining C-matchers with **defcmatcher**

A c-matcher gives C code template for testing the matched data and for filling the extracted sub-data.

```
;; match a gimple cast assign
(defcmatcher gimple_assign_cast
  (:gimple ga) ;match
  (:tree lhs ;left hand side
   :tree rhs ;first right operand
  ) ;outs
  gimpascs
  ;;test expansion
  #{/*$gimpascs test*/($ga && gimple_assign_cast_p ($ga))}#
  ;;fill expansion
  #{/*$gimpascs fill*/
   $lhs = gimple_assign_lhs($ga);
   $rhs = gimple_assign_rhs1($ga);
  }#
)
```

When defining your c-matcher, be cautious: the matched data μ can be cleared!

Defining your matcher with a MELT function

You can define your fun-matcher with a MELT function, which returns primarily nil on failure and a non-nil value[58] on success.
When the match succeeds, the filled data is given thru secondary results.

```
1  (defun matchbiggereven (fmat :long m :long n)
2     (if (==i (%iraw m 2) 0)
3         (if (>i m n)
4             (let ( (:long h (/iraw m 2)) )
5               (return fmat h) ;; succeed, gives h
6               )))
7     ;; fails
8     (return))
9  (defunmatcher isbiggereven
10   ;; the input formals; first is the matched input...
11   (:long m n)
12   ;; the output formals
13   (:long o)
14   ;; the matching function
15   matchbiggereven)
```

Then `?(matchbiggereven 5 ?n)` would match some long stuff m, if it is even $m = 2n$ and $m > 5$ and bind `n` to n

[58] E.g. `:true` or here the matcher `fmat`

matching translation

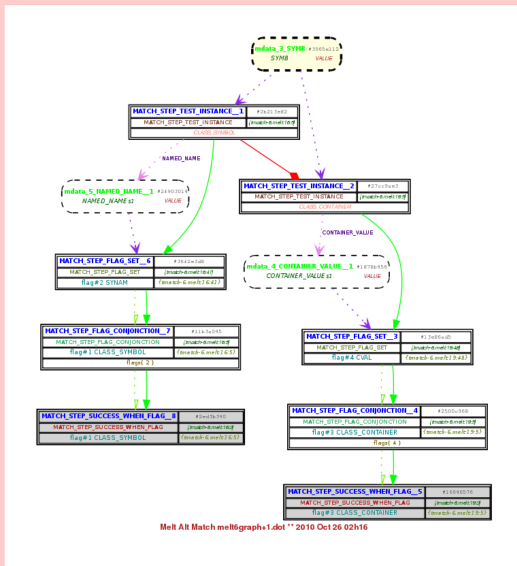
A first version of the pattern matching translator is ad-hoc (but try to share sub-pattern matching).

A second version[59] makes a graph of tests

```
1 (defun testnameofsymbol (symb f g)
2   (match symb
3           ( ?(instance class_symbol :named_name  ?synam)
4             (f synam))
5           ( ?(instance class_container :container_value ?cval)
6             (g cval))))
```

gets translated into the following graph

[59] almost done, very experimental


mdata_3_SYMB
SYMB
VALUE
MATCH_STEP_TEST_INSTANCE__1
MATCH_STEP_TEST_INSTANCE
CLASS_SYMBOL
NAMED_NAME
mdata_5_NAMED_NAME__1
NAMED_NAME s1
VALUE
MATCH_STEP_TEST_INSTANCE__2
MATCH_STEP_TEST_INSTANCE
CLASS_CONTAINER
CONTAINER_VALUE
MATCH_STEP_FLAG_SET__6
MATCH_STEP_FLAG_SET
flag#2 SYNAM
mdata_4_CONTAINER_VALUE__1
CONTAINER_VALUE s1
VALUE
MATCH_STEP_FLAG_CONJONCTION__7
MATCH_STEP_FLAG_CONJONCTION
flag#1 CLASS_SYMBOL
flags{ 2 }
MATCH_STEP_FLAG_SET__3
MATCH_STEP_FLAG_SET
flag#4 CVAL
MATCH_STEP_SUCCESS_WHEN_FLAG__8
MATCH_STEP_SUCCESS_WHEN_FLAG
flag#1 CLASS_SYMBOL
MATCH_STEP_FLAG_CONJONCTION__4
MATCH_STEP_FLAG_CONJONCTION
flag#3 CLASS_CONTAINER
flags{ 4 }
MATCH_STEP_SUCCESS_WHEN_FLAG__5
MATCH_STEP_SUCCESS_WHEN_FLAG
flag#3 CLASS_CONTAINER
Melt Alt Match melt6graph+1.dot ** 2010 Oct 26 02h16

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Your passes in MELT

- define your own MELT modes (using **class_melt_mode** and **install_melt_mode**).
- define and install your GCC passes coded in MELT
- if needed, define missing glue (primitives, c-matchers, c-iterators, ...)
- use pattern matching extensively
- MELT values can be shared between GCC passes coded in MELT (thru instances defined by **definstance**, by closing values, etc.). For instance, you could have a first pass filling some MELT object with a basic block hash map assocating MELT closures to `basic_block`-s, and a later pass choosing some of the basic block and applying the associated closure.

There are lots of existing MELT names gluing many GCC API names. Look into documentation or `grep` the `*.melt` code.

useful MELT features for adding GCC passes

```
1  (defclass class_gcc_pass
2    :predef CLASS_GCC_PASS
3    :super class_named
4    :fields (gccpass_gate                          ;closure for gate
5             gccpass_exec                          ;closure for execution
6             gccpass_data                          ;extra data
7             gccpass_properties_required
8             gccpass_properties_provided
9             gccpass_properties_destroyed
10            gccpass_todo_flags_start
11            gccpass_todo_flags_finish
12            ))
13 (defclass class_gcc_gimple_pass
14   :predef CLASS_GCC_GIMPLE_PASS
15   :super class_gcc_pass)
16 (defclass class_gcc_rtl_pass
17   :predef CLASS_GCC_RTL_PASS
18   :super class_gcc_pass)
19 (defclass class_gcc_simple_ipa_pass
20   :predef CLASS_GCC_SIMPLE_IPA_PASS
21   :super class_gcc_pass)
```

and the `install_gcc_pass` primitive.

debugging help

You usually don't want to debug the MELT generated C code under `gdb`[60]

The `-fmelt-debug` program argument to `gcc-melt` gives lot of (uniquely numbered) debugging output messages.

The `-fmelt-debugskip=1234` program argument skips the first 1234 debugging messages

To get your own debugging messages

- Debug display a value with **debug_msg**:

```
(debug_msg curval "this is curval")
```

- debug display a stuff, e.g. a raw `gimple` or `tree`, with `debuggimple`, `debugtree` primitives[61] etc ...

Such debug messages also show their source location in MELT source file.

---

[60] However, your MELT module knows about the MELT source code location because MELT generates lots of `#line` directives, which can be disabled

[61] The debugged stuff is the first argument, the message string the second one!

adding runtime assertions

The `assert_msg` syntax checks an assertion at runtime:
`(assert_msg` μ τ`)` $\Rightarrow$ When `ENABLE_CHECKING`, if the test τ is false, display the message μ, the MELT call stack, and `fatal` error.

```
;; -*- lisp -*- ; public domain file assertex.melt
(defun chokeme (x :long t)
  (debug_msg x "chokeme got x")
  (assert_msg "choke me got a zero t" t))
(defun dobad (x y)
  (debug_msg y "has x")
  (if (== x y) (chokeme x 0)))
(dobad 'b (multiple_nth (tuple 'a 'b 'c) 1))
```

debugging aid helps!

shell run 9

```
gcc-melt -fmelt-mode=runfile -fmelt-arg=assertex.melt -fmelt-debug -c
empty.c
```

⇒

```
#4:<RUNFILE_DOCMD @warmelt-outobj.melt:4002> warmelt-outobj.melt:4030:/ clear
#5:_ melt-runtime.c:9546 <do_initial_mode before apply>
#6:_ melt-runtime.c:9760 <load_initial_melt_modules before do_initial_mode> .

@assertex.melt:42: start initialize_module_meltdata_assertex iniframp__=0x7fff03afa1
!!!!****####1743#^6:assertex.melt:6:has x !1: 'B|CLASS_SYMBOL/bad961
!!!!****####1744#^7:assertex.melt:3:chokeme got x !1: 'B|CLASS_SYMBOL/bad961
cc1: error: MELT fatal failure from assertex.melt:4 [MELT built Oct 19 2010]

SHORT BACKTRACE[#1744] MELT fatal failure;
#1:<CHOKEME @assertex.melt:2> assertex.melt:4:/ cond.else
#2:<DOBAD @assertex.melt:5> assertex.melt:7:/ cond
#3:_ assertex.melt:8:/ apply
#4:_ melt-runtime.c:7155:meltgc_make_load_melt_module before calling module asserte
#5:<RUNFILE_DOCMD @warmelt-outobj.melt:4002> warmelt-outobj.melt:4030:/ clear
#6:_ melt-runtime.c:9546 <do_initial_mode before apply>
#7:_ melt-runtime.c:9760 <load_initial_melt_modules before do_initial_mode> .

cc1: error: MELT failure with loaded module #1: /usr/local/libexec/gcc-melt/gcc/x86_
```

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Try to use MELT by yourself

- most of the MELT reference documentation[62] is generated[63] from MELT source code (using `:doc` annotations)
- Learn more about MELT by looking into generated documentation... `make pdf` in the MELT branch

  Generating documentation from code brings “interesting” issues[64]. Perhaps MELT reference documentation (mostly generated) will be GPL-ed?
- ask me for help if needed in english on `gcc@gcc.gnu.org`, in french on `gcc-melt-french@googlegroups.com`
- patch the MELT branch (e.g. if some primitives are missing)

[62] Which is very incomplete on october 2010

[63] In file `gcc/meltgendoc.texi` in the build tree

[64] See `http://gcc.gnu.org/ml/gcc/2010-10/msg00242.html`

Who uses MELT?

- (my former intern) Jérémie Salvucci `jeremie.salvucci@free.fr`:
  1. added several needed glues (cmatchers, primitives)
  2. coded a translator[65] in MELT from Gimple to low-level C for the free Frama-C `http://frama-c.com/` static analyzer[66]
  3. coded (with me) the gengtype patches for plugins[67]
- Marie Krumpe (intern of Emmanuel Chailloux, LIP6 [Paris 6 Univ.]) explored generation of low-level C++ code from Gimple for the Cadna `http://www.lip6.fr/cadna` free software library[68]
- Alexandre Pelissy (Mandriva and PhD student at Univ.Tours) - with Pierre Vittet are starting to use MELT for analysis of the linux kernel code
- I am continuing to enhance MELT and will use for generation of OpenCL code `www.opengpu.net`[69]
- **you are welcome** to use it!

---

[65] Partially working

[66] Developed in Ocaml by my CEA collegues and INRIA people; free software LGPL licensed

[67] Work being submitted to the trunk in october 2010

[68] estimating accuracy of IEEE 754 floating computations

[69] Perhaps using Graphite-OpenCL?

future work

- bug corrections
- (in progress) improving the translation of `match` expressions
- minor MELT language and runtime improvements
  e.g. simpler program arguments
- good LTO support in MELT
- more MELT language features (rewriting MELT macro-s à la Scheme, patterns in `let`, . . .)
- memoizing method lookup
- adding more c-types when needed
- real GCC passes coded in MELT

technical points

LTO $\Rightarrow$ serialization of MELT values

- sharing MELT values between several `*.o`
- serialization of closures (but MELT closures know the C name of their routines!)
- ...

Take profit of better `gengtype`
(generate some runtime code from `gtype.state`?)

wishes

MELT can be used to experiment new middle-end passes in GCC
It can also be used for specific GCC extensions. For library- or software-specific MELT extensions to GCC, the best experts are from that software community

- GTK would need several MELT extensions to
  1. type-check `g_object_set`
  2. check coding conventions
  3. etc
- the Linux kernel will benefit from GCC extensions coded in MELT
- major free software[70] compiled with GCC could benefit from MELT

Long term dream: perhaps pushing MELT into the trunk, e.g. as a help to developers? MELT as a `tree-browser` on steroids?[71]
Or maybe, MELT should stay as a GCC plugin example?

[70] Intuitively, any large enough $\geq 1 MLOC$ free software could develop its own GCC extensions in MELT for its own use, and using MELT should be less hard than coding plugins in C!

[71] The `gcc/tree-browser.c` is useful for GCC developers. Perhaps MELT may be useful for them also?

To help me...

- compile and use MELT
- explain me LTO streaming
- explain me how to make test-cases (dejagnu scripts for MELT?)
- explain me **why MELT didn't exist before?**
  GCC has a lot of code generators already! (why not in the middle-end?)
- suggest better building scheme for MELT (`Makefile`-s)?

Thanks! Questions?