GCC internals and *MELT* extensions

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Basile STARYNKEVITCH
basile@starynkevitch.net (or basile.starynkevitch@cea.fr)

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disclaimer: opinions are mine only

Opinions expressed here are only mine!

- not of my employer (CEA, LIST)
- not of the Gcc community
- not of funding agencies (e.g. DGCIS)[1]

I don't understand or know all of Gcc;
there are many parts of Gcc I know nothing about.

Beware that **I have some strong technical opinions** which are not the view of the majority of contributors to Gcc.

I am not a lawyer ⇒ don't trust me on licensing issues

(many slides copied from previous talks)

[1] Work on Melt have been possible thru the GlobalGCC ITEA and OpenGPU FUI collaborative research projects, with funding from DGCIS

Expected audience

Audience is expected to be familiar with:

- GNU/Linux (or other Unix) command line tools like `emacs` or `vim`, shell, Gnu `make`, Gnu `awk`, debugger like `gdb`, `svn` or `git` etc...
- "daily" usage of **gcc** (for e.g. *C* or *C++* code); you should know the basic Gcc options like `-c`, `-Wall`, `-I`, `-g`, `-O2` ...
- some experience in building free software
- knowing some other language (like Scheme, Python, Ocaml, ...) is helpful but not required
- having a GNU/Linux laptop may help (4Gb RAM, 12Gb disk space); having `gcc-4.7` with plugins enabled also help

You are not expected to be fluent with:

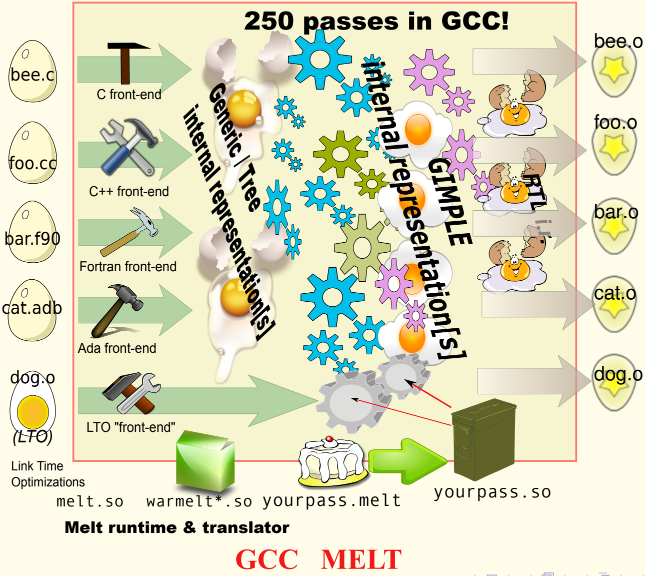
- compiler techniques in general (including parsing techniques)
- Gcc internals
- Melt internals
- Lisp languages

GCC (Gnu Compiler Collection) `gcc.gnu.org`

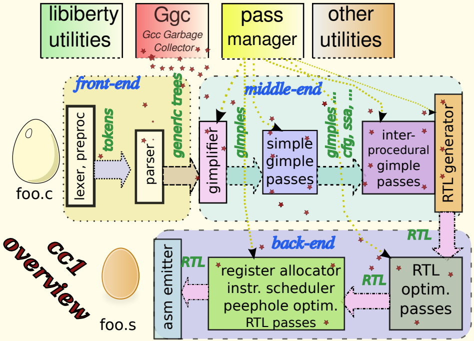
- perhaps **the most used compiler** : your phone, camera, dish washer, printer, car, house, train, airplane, web server, data center, Internet have Gcc compiled code
- [cross-] compiles **many languages** (C, C++, Ada, Fortran, Go, Objective C, Java, ...) **on many systems** (GNU/Linux, Hurd, Windows, AIX, ...) for **dozens of target processors** (x86, ARM, Sparc, PowerPC, MIPS, C6, SH, VAX, MMIX, ...)
- **free** software (GPLv3+ licensed, FSF copyrighted)
- **huge** (**5** or 8? **MLOC**), **legacy** (started in **1985**) software
- still **alive** and **growing** (+6% in 2 years)
- **big** contributing **community** ($\approx$ **400** “maintainers”, mostly full-time professionals)
- **peer-reviewed** development process, but **no main architect** $\Rightarrow$ (IMHO) “sloppy” software architecture, not fully modular yet
- **various coding styles** (mostly *C & C++* code, with some **generated *C* code**)
- **industrial-quality compiler** with **powerful optimizations** and **diagnostics** (lots of tuning parameters and options...)

Current version is `gcc-4.7.0` (octobermarch 2012).

Gcc & Melt


250 passes in GCC!
bee.c
foo.cc
bar.f90
cat.adb
dog.o
(LTO)
Link Time
Optimizations
C front-end
C++ front-end
Fortran front-end
Ada front-end
LTO "front-end"
Generic / Tree
internal representation[s]
internal representation[s]
GIMPLE
RTL
bee.o
foo.o
bar.o
cat.o
dog.o
melt.so
warmelt*.so
yourpass.melt
yourpass.so
Melt runtime & translator
GCC MELT

cc1 organization



Gcc is really cc1

- **3 layers :** front-ends → a **common middle-end** → back-ends
- accepting **plugins**
- utilities & (meta-programming) *C* **code generators**
- **internal representations** (Generic/Tree, Gimple[/SSA], CFG ...)
- **pass manager**
- Ggc (= Gcc garbage collection)

plugins and extensibility

- infrastructure for plugins started in **`gcc-4.5`** (april 2010)
- `cc1` can `dlopen` user plugins[2]
- plugin **hooks** provided:
  1. a plugin can **add** its own **new passes** (or remove some passes)
  2. a plugin can handle **events** (e.g. Ggc start, pass start, type declaration)
  3. a plugin can accept its own **`#pragma`**-s or **`__attribute__`** etc...
  4. ...
- plugin writers need to **understand Gcc internals**
- plugin may provide **customization** and application- or **project- specific** features:
  1. specific warnings (e.g. for untested `fopen` ...)
  2. specific optimizations (e.g. `fprintf(stdout, ...)` → `printf(...)`)
  3. code refactoring, navigation help, metrics
  4. etc etc ...
- coding plugins in ***C*** may be **not cost-effective**
  higher-level languages are welcome!

[2] Gcc plugins should be free software, GPLv3 compatible

extending GCC with an existing scripting language

A **nearly impossible task**, because of **impedance mismatch**:

- rapid evolution of Gcc
- using a a scripting language like Ocaml, Python[3] or Javascript[4] is difficult, unless focusing on a tiny part of Gcc
- **mixing several unrelated G-Cs** (Ggc and the language one) is **error-prone**
- the Gcc internal API is ill-defined, and has non “functional” sides:
  1. extensive use of *C* macros
  2. ad-hoc iterative constructs
  3. lots of low-level data structures (possible performance cost to access them)
- the Gcc API is huge, and not well defined (a bunch of header files)
- needed **glue code** is big and would change often
- Gcc extensions need **pattern-matching** (on existing Gcc internal representations like *Gimple* or *Tree*-s) and high-level programming (functional/applicative, object-orientation, reflection).

---

[3] See Dave Malcom’s Python plugin

[4] See TreeHydra in Mozilla

extending GCC with **MELT**

Melt[5] is a high-level **D**omain **S**pecific **L**anguage for Gcc extensions:

- simple **Lisp-like syntax** (parenthesis)
- **dynamically typed values** (boxed Gcc data, objects, hash-tables, tuples, closures)
- able to handle raw **native** Gcc low-level **stuff** and Melt **values**
- garbage-collected
- powerful **pattern-matching**
- **translated** to **generated** *C* code
  bootstrapped, i.e. the Melt translator is coded in Melt
- able to mix *C* code in *MELT* code
- freely available (as the `melt.so` meta-plugin), with GPLv3+ license
  `http://gcc-melt.org/`
- some projects did use MELT, e.g. **Talpo** by Pierre Vittet

[5] Used to be an acronym for **M**iddle-**E**nd **L**isp **T**ranslator

Other approaches

To work on internal source code representations:

- text-like approaches `awk`, `grep`, `sed`, `perl` ☹
- static analyzers:
  1. costly commercial tools (Coverity™, Polyspace™, Astrée™, Eclair™...)
  2. some free static analyzers (Frama-C `http://frama-c.com/`)

  but using external tools may disrupt developers' habits, and there may be semantic differences with what the compiler does.
- some compilers are also extensible e.g. **Llvm/Clang**

  (nobody knows well both `clang/llvm` and `gcc` internals)
- some integrated development environment (Eclipse) or editors (Emacs)

To improve code generation:

- fork a compiler or write your own ☺
- post-processor on the assembler ☹
- patch the binary ☹

Installing MELT - prerequisites

Since Melt is a C code generator, you need to have all the dependencies for compiling GCC itself. Having the GCC 4.7 source code is helpful, to look inside.

On Debian (testing or sid) or Ubuntu, install the following packages:

- the Gcc 4.7 **compiler binary** packages:
  `apt-get install gcc-4.7 g++-4.7 gcc-4.7-multilib`
- all **the dependencies to build Gcc** from its source code:
  `apt-get build-dep gcc-4.7`
- the Gcc 4.7 **plugin development** package:
  `apt-get install gcc-4.7-plugin-dev`
- the **Parma Polyhedra Library** [6] is required, with its *C* interface:
  `apt-get install libppl-dev libppl-c-dev`

Caveat: some distributions don't have GCC 4.7, and some distributions don't enable plugins inside it. If unlucky, you might have to compile GCC 4.7 from its source code. Building GCC 4.7 from source is tricky, needs care and time.

[6] the PPL is a prerequisite to GCC. See `http://bugseng.com/products/ppl/`

Compiling and installing MELT

1. check the configured features of your Gcc with **`gcc -v`** and **subscribe** to `gcc-melt@googlegroups.com`
2. retrieve the latest MELT plugin source code:
   `wget http://gcc-melt.org/melt-0.9.5-plugin-for-gcc-4.6-or-4.7.tar.gz`
3. untar the archive:
   `tar xzvf melt-0.9.5-plugin-for-gcc-4.6-or-4.7.tar.gz`
   this will create and fill a `melt-0.9.5-plugin-for-gcc-4.6-or-4.7/` directory
4. go into that new directory: **`cd melt-0.9.5-plugin-for-gcc-4.6-or-4.7`**
5. look into the `MELT-Plugin-Makefile` or `Makefile` (a symlink).
   The default settings are common, but you could want to change some of them in the first 110 lines with an editor. Usually no changes are required.
6. build the Melt **[meta-] plugin** with Gnu **`make`** (don't do a parallel make)
   The build usually takes less than **ten minutes**.
7. build the installed tree: **`make install DESTDIR=/tmp/meltinst`**
8. copy as root the installed tree: **`sudo cp -v -a /tmp/meltinst/ /`**
   the files are installed under your Gcc plugin directory

Installed MELT tree

The Melt software is installed under the Gcc plugin directory, as given by **`gcc -print-file-name=plugin`**. (On my Debian/Sid system it is `/usr/lib/gcc/x86_64-linux-gnu/4.6/plugin/`):

- the Melt meta-plugin **`melt.so`** contains the Melt runtime[7] (garbage collector, low level routines).
- the **`include/`** directory (which already contained Gcc plugin headers) gets Melt header files **`include/melt*.h`**; in particular the file `include/melt-run.h` contains many `#include`-s, since it is the only header file `#include`d by Melt generated *C* code.
- the **`melt-module.mk`** file is for Gnu `make` started by the Melt runtime.
- the **`melt-sources/`** directory (more than 80 files) is required for operation, and contains the Melt source code (e.g. `xtramelt-ana-base.melt`), the corresponding generated *C* code (e.g. `xtramelt-ana-base*.c`), in particular the module descriptive and timestamp *C* code (e.g. `xtramelt-ana-base+meltdesc.c` and `xtramelt-ana-base+melttime.h`).

[7] Some of the runtime routines are Melt generated!

Installed MELT tree (2)

- the **`melt-modules/`** directory (> 40 files) contains the binary shared object modules[8] dynamically loaded by the Melt runtime.

Each module may come in different **flavors** (e.g. optimization level by the *C* compiler which compiled the generated *C* code):

- **`optimized`** : optimized with `-O2`, no debugging code
- **`quicklybuilt`** : non-optimized, with debugging code
- **`debugnoline`** : compiled with `-g` for `gdb` debugging, with debugging code, without `#line` directives enabled.

The module file path contains the `md5sum` of the catenation of the *C* source code. E.g.

`xtramelt-ana-base.5366195dcef243ff011635480216ea65.optimized.so`

[8] These `*.so` files are `dlopen`-ed by the `melt.so` Gcc [meta-] plugin, but follow different conventions than Gcc plugins

More on MELT modules

Conceptually, the Melt system is "loading" the generated *C* source code of each module, and parses the `*+meltdesc.c` file when loading a module.

The module directory is conceptually a cache, when some `*.so` is not found it is regenerated by forking a `make` using the `melt-module.mk` file.

From the user's point of view, most of the time is spent in compiling the generated *C* file.

The Melt installation procedure translates several times the translator's `warmelt-*.melt` files into generated *C* files.

The `melt-sources/` directory also contains the file **`melt-sources/melt-default-modules.modlis`**, containing the list of default modules to be loaded by Melt.

Melt expects the `*.melt` source files to be available.
The GCC runtime exception sort-of "requires" Gcc extensions to be free software. `http://www.gnu.org/licenses/gcc-exception.html` (you are probably not allowed to distribute a proprietary binary compiled by an extended Gcc compiler, if the extensions are not free software)

Using MELT plugin

You need a Gcc **4.7** (or future `4.8`, or past `4.6`) with the Melt [meta-]plugin built and **installed** to use Melt.

You need to give to **`gcc`** the program argument **`-fplugin=melt`** to ask Gcc to load the Melt [meta-] plugin. This should be given first, just after `gcc`. Required or useful options (specific to Melt):

- **`-fplugin-arg-melt-mode=`**μ to set the **mode** to μ; the Melt plugin don't do anything without a mode. Melt provides several modes, and your Melt extensions usually install their own mode[s], which you have to give. Use the **`help`** mode to get a list of them.
- **`-fplugin-arg-melt-workdir=`**δ to give a working directory δ for Melt (which will contain generated modules, etc...). The work directory is usally the same for all the Melt-enhanced Gcc executions inside a project.
- **`-fplugin-arg-melt-arg=`**α to give an extra argument α for Melt (usually mode specific)

Other useful Melt program options

- **-fplugin-arg-melt-extra=**ξ_1**:**ξ_2 ... - a colon separated list of your extra modules (often a single one) to load.
- **-fplugin-arg-melt-debug** or **-fplugin-arg-melt-debugging=mode** or **all** to get debugging information, assuming a `quicklybuilt` or `debugnoline` flavor of modules (with debugging code)
- **-fplugin-arg-melt-debug-skip=**σ to skip the first σ debugging messages
- **-fplugin-arg-melt-print-settings** to output the builtin settings in `/bin/sh` compatible form
- **-fplugin-arg-melt-source-path=**σ_1**:**σ_2 - a colon separated path for Melt source directories (with `*.melt` and generated `*.c`)
- **-fplugin-arg-melt-module-path=**μ_1**:**μ_2 - a colon separated path for Melt module directories (with `*.optimized.so` and `*.quicklybuilt.so`)
- **-fplugin-arg-melt-init=...** - colon seperated list of initial modules or **@** module lists
- etc . . .

MELT is **not** a GCC front-end

. . . because a Gcc plugin cannot add a new language.

⇒ **to translate a Melt source file, run `gcc` on** e.g. **some** empty **file** :

```
gcc -fplugin=melt -c \
  -fplugin-arg-melt-mode=translatequickly \
  -fplugin-arg-melt-arg=ex01m-helloworld.melt \
  -fplugin-arg-melt-workdir=meltworkdir/ \
 empty-file-for-melt.c
```

Melt is also able to run directly a `*.melt` file with `-fplugin-arg-melt-mode=runfile`: a temporary generated *C* file is produced, compiled (with `make`) into a module, and dynamically loaded with `dlopen` (all from the same `cc1` process initiated by `gcc`).

ex.1 *"Hello World"* in MELT

```
;; -*- Lisp -*-    (for Emacs).          file ex01m-helloworld.melt
;; following comment appearing in the generated C file:
(comment "file ex01-helloworld.melt is in the public domain")
(code_chunk hellochk
  #{ printf("Hello by $HELLOCHK from %s at %d\n", __FILE__, __LINE__); }#
)
```

- **Lisp**-like syntax: **(** *operator operands ...* **)** **parenthesis are important**
  ⇒ `(f)` is never the same as `f`
- Embed ***C* code chunks** in your Melt code with **macro-strings** **#{** ... **}#**

Running it with:

```
gcc -fplugin=melt -fplugin-arg-melt-mode=nop \
    -fplugin-arg-melt-extra=ex01m-helloworld -c empty-file-for-melt.c
```

Output is `Hello by HELLOCHK__1 from ex01m-helloworld.melt at 5`

- source location in Melt code kept (by emission of `#line` directives)
- unique substitution of **state symbol** `hellochk`

simple advices for MELT

- use a lisp mode in your editor for your Melt extensions (in `*.melt` files)
- subscribe to `gcc-melt@googlegroups.com`
- the base name of your Melt extensions should be different of your compiled *C* or *C++* files (e.g. don't have a `foo.melt` to compile your `foo.cc`)
- always provide a work directory (with `-fplugin-melt-arg-workdir`)
- use Melt crude debugging features; avoid `gdb` on your Melt extensions
- be very careful when embedding *C* code chunks inside Melt code[9]
- possible GNU `make` rule:

```
%.quicklybuilt.so: %.melt | empty-file-for-melt.c meltworkdir
        gcc -fplugin=melt -fplugin-arg-melt-mode=translatequickly \
            -fplugin-arg-melt-arg=$^  \
            -fplugin-arg-melt-output=$@  \
            -fplugin-arg-melt-workdir=meltworkdir/  \
            -c empty-file-for-melt.c
```

- use `quicklybuilt` flavor for development of Melt code (and `optimized` for deployment). The bottleneck is the compilation of the generated *C* code!

[9] When novice in Melt, avoid memory allocation inside *C* code chunks.

Basic (lisp-like) lexical and syntactic rules of Melt

- case is not significant: so `iF` ≡ `IF` ≡ `if` [10] (conventionally prefer lower case)
- identifiers or **symbols** may contain special characters: `+ivi` is a symbol
- comments start with semi-colon `;` up to EOL.
- a Melt file contains expressions. Some have defining or side- effects.
  ⇒ **Melt has no instructions!** Expressions are evaluated in sequence.
- **all expressions** are `(` ***`operand operators`*** ... `)`
- macro-strings are lexical (transformed to list of strings or names)
  `#{foo\$BAR#x1}#` → `("foo\\" bar "x1")`
- some **syntactic sugar**:
  - `'`τ ≡ `(quote` τ`)` [for quotation of constants]
  - `!`ξ ≡ `(exclaim` ξ`)` [for content access]
  - `?`π ≡ `(question` π`)` [for patterns]
- **"keywords"** starting with colon e.g. `:else` usually not evaluated

NB: "symbol" and "keyword" are lisp terminology

[10] It is symbol, often understood as a conditional

Melt idiosyncrasy : **values ≠ stuff**

1. **values** (e.g. objects, boxed integers, tuples, lists, closures, boxed stuff)
   - "dynamically typed" (like in Lisp, Python, Scheme, Ruby, ...); each value has a **discriminant**
   - first-class citizen: can be argument, reciever, result, fields, closed, ...
   - implicit kind of most data
   - **prefer to handle values** in your code
   - efficiently garbage collected by Melt (quick allocation)
   - `'1` ≡ `(quote 1)` denotes a boxed integer value one (of `discr_constant_integer`); `()` is the nil value
2. **stuff** = low level data handled inside Gcc (e.g. raw longs, gimples, trees, ...)
   - statically typed, often with c-type annotations like **`:long`** or **`:tree`**
   - restricted usage in Melt (e.g. a Melt function cannot give stuff as it primary result, only as secondary ones)
   - directly translated to *C* counterpart
   - some stuff is garbage collected by Gcc only (but not all, e.g. **`:cstring`** for constant character strings)
   - `0` denotes a stuff of c-type `:long` ⇒ so `0` ≢ `'0` unlike in Lisp-s
   - **sadly** unavoidable, hence sometimes **useful**
   - **avoid stuff when you can**

Important **stuff** (e.g. internal Gcc representations)

Thru their Melt c-type “keywords”

- **:long** for raw integer `long` numbers.
  Not sufficient for target integers. See `HOST_WIDE_INT` inside Gcc
- **:cstring** for `const char*` string constants **outside of heap** (only literal strings like `"message"`).
- **:tree** for Gcc `tree`-s, a (pointer like) opaque type for abstract syntax tree (e.g. declarations) inside Gcc.
- **:gimple** for Gcc elementary *Gimple* instructions (3-address like). Their operands are `:tree`-s
- **:gimple_seq** for Gcc sequence of *Gimple*-s
- **:basic_block** for Gcc basic blocks containing *Gimple* sequences
- **:edge** for control flow graph edges between basic blocks
- etc etc. Adding a new c-type is fairly easy (require full Melt regeneration).

NB: **:value** is the c-type for values

Contents

ex.2 Counting functions in your *C* or *C++* code

We want to count the (*C*, *C++*, ...) functions as compiled by your extended Gcc.

1. define the counter object value
2. define the counting function (incrementing that counter value)
3. define a Melt mode gluing it into the Gcc pass machinery
4. illustrate some basic Melt constructs
   (most defining constructs start with `def`... like `defun` or `definstance`)
5. understanding the Gcc [powerful] “mess”

NB: Our examples are available at
`git://github.com/bstarynk/melt-examples.git`
(public domain or LGPLv3)

defining the counter object

We define an instance of `class_container`, we name it `fun_counter`

Example

```
(definstance  fun_counter class_container
      :container_value '0)
```

The symbol **`definstance`** is for **static definitions of object instances**

Notice the unique field `container_value` initialized to a **boxed integer** value `'0` *(omitting the quote gives an error)*

To access the contained value [11]

`(get_field :container_value fun_counter)` or simply **`!fun_counter`**

[11] It is a safe access: won't crash if `fun_counter` was not of `class_container`

incrementing the counter value

Our incrementing function has no arguments and gives no result (so returns nil)

Example

```
(defun countfun_pass_exec ()
  (set_content fun_counter (+ivi !fun_counter 1))
  (debug "incremented fun_counter=" fun_counter))
```

- formal argument list `()` is empty
- function body has two expressions (the last can give the result)
- use **debug** to display debug messages (when **`-fplugin-arg-melt-debug`** given)
- `+ivi` [add **i**nteger **v**alue with **i**nteger stuff] is a **primitive** operation
- `(set_content fun_counter` ξ`)`
  $\equiv$ `(put_fields fun_content :container_value` ξ`)`
  is [safely] updating an object value

Our function is called `countfun_pass_exec` because it is related to Gcc pass execution...

let there be locally scoped variables ...

Later we need to inform the user. We need the number stuff inside the counter object, but it is only of local interest. Use the `let` construct, with a sequence of bindings and a body of sub-expressions.

```
(let ( (:long nbcount (get_int !fun_counter))
     )
  (code_chunk
   informusercount
   #{ /*$INFORMUSERCOUNT*/ inform(UNKNOWN_LOCATION,
                  "MELT counted %ld functions / $INFORMUSERCOUNT",
                  $NBCOUNT) ;
   }#))
```

NB: outside of that `let` the `nbcount` variable is unknown (unbound) there is a lexical scope for variables.

Of course the above `let` is inside something, an anonymous function...

anonymous functions at last

The **lambda** syntax introduces an anonymous function. Here we register it to be called at exit (in a first to last order).

```
(at_exit_first
 (lambda ()
  ;; same as previous slide:
  (let ( (:long nbcount (get_int !fun_counter)) )
    (code_chunk informusercount
     #{ /*$INFORMUSERCOUNT*/ inform(UNKNOWN_LOCATION,
          "MELT counted %ld functions / $INFORMUSERCOUNT",
          $NBCOUNT) ;

     }#))
))
```

The `fun_counter` is closed inside the `lambda` (only values, not stuff, can be closed). So `lambda` expressions **evaluate** to **closures** (= code + closed values).

Functional values (notably with anonymous `lambda`) are very **powerful**: put them inside objects, tables, containers, tuples . . . and apply them much later!

Making a pass on command

```
(defun funcounter_docmd (cmd moduldata)
  (debug "funcounter_docmd cmd=" cmd)
  (let ( (countfunpass
      (instance class_gcc_gimple_pass
                     :named_name '"countfun_pass"
                     :gccpass_exec countfun_pass_exec))
         )
    (install_melt_gcc_pass countfunpass "after" "cfg" 0)
    (debug "countfunpass=" countfunpass)
    [inform at exit, as before]
    (debug "funcounter mode success cmd=" cmd)
    (return :true)
    ))
```

- `instance` dynamically creates a new object instance value
- a Gcc *Gimple* **pass** is created and **installed** after an existing one named `"cfg"` (control flow graph builder)
- the `funcounter_docmd` function (for our mode) should return non-nil to succeed. We use the `return` syntax for clarity[12]

[12] Since the `(return :true)` expression is the *last* of the function's body, it already gives the returned value and could be just `:true`

defining and installing our mode

```
(definstance funcounter_mode  class_melt_mode
  :named_name '"funcounter"
  :meltmode_help '"install a pass to count functions"
  :meltmode_fun funcounter_docmd)

(install_melt_mode funcounter_mode)
;; eof ex02m-countfun.melt
```

Then we can use our extension:

```
gcc -fplugin=melt -O -fplugin-arg-melt-mode=funcounter \
    -fplugin-arg-melt-workdir=meltworkdir \
    -fplugin-arg-melt-extra=ex02m-countfun -c ex02c-sample.c
cc1: note: MELT counted 3 functions / INFORMUSERCOUNT__1
```

NB: we could have translated our Melt code and used it in the same `gcc` with `-fplugin-arg-melt-mode=runfile,funcounter`

ex.3 learn more about passes, using a MELT hook

```
;; file ex03m-passhook.melt
(defun passhook (passname :long passnum)
   (debug "passhook passname=" passname " passnum=" passnum)
   (shortbacktrace_dbg "passhook" 10)
   (code_chunk passhookchk
         #{/*$PASSHOOKCHK*/ printf("passhook %s #%d\n",
                                   melt_string_str ($PASSNAME),
                                   (int) $PASSNUM);}#))
(register_pass_execution_hook  passhook)
```

- example of formal arguments list with raw stuff (here `passnum`)
- all Melt functions have, if any, their **first argument a value**
- **`shortbacktrace_dbg`** to print the call stack (for debugging purposes)
- careful use of **`melt_string_str`** *C* function
  the **:cstring** c-type is not garbage collected, and is not compatible with Melt boxed strings
- use **`register_pass_execution_hook`** (often inside a mode) to register a Melt hook called for each executed pass.

showing the passes when our Gcc runs

With a tiny example file **ex03c-twofun.c**

```
int two = 2;
int first(int x)
{
  return x*two;
}
int second(int y, int z)
{
  return y+z+two;
}
/* eof ex03c-twofun.c */
```

compiled by

```
gcc -fplugin=melt -O -fplugin-arg-melt-mode=nop \
    -fplugin-arg-melt-workdir=meltworkdir \
    -fplugin-arg-melt-extra=ex03m-passhook -c ex03c-twofun.c
```

GCC runs many (290) passes!

```
passhook *warn_unused_result #-1
passhook omplower #13
passhook lower #14
passhook eh #16
passhook cfg #17
passhook *warn_function_return #-1
passhook *build_cgraph_edges #-1
passhook *warn_unused_result #-1
passhook omplower #13
passhook lower #14
passhook eh #16
passhook cfg #17
passhook *warn_function_return #-1
passhook *build_cgraph_edges #-1
passhook *free_lang_data #-1
passhook visibility #18
passhook early_local_cleanups #19
passhook *free_cfg_annotations #-1
passhook *init_datastructures #-1
passhook *referenced_vars #-1
passhook ssa #21
passhook veclower #22
passhook *rebuild_cgraph_edges #-1
passhook inline_param #23
passhook einline #24
passhook early_optimizations #25
passhook *remove_cgraph_callee_edges #-1
passhook copyrename #26
passhook ccp #27
passhook forwprop #28
passhook ealias #29
passhook esra #30
passhook copyprop #31
passhook mergephi #32
passhook cddce #33
passhook profile #38
passhook local-pure-const #39
passhook release_ssa #41
passhook *rebuild_cgraph_edges #-1
passhook inline_param #42
passhook *free_cfg_annotations #-1
passhook *init_datastructures #-1
passhook *referenced_vars #-1
passhook ssa #21
passhook veclower #22
passhook *rebuild_cgraph_edges #-1
passhook inline_param #23
passhook einline #24
passhook early_optimizations #25
passhook *remove_cgraph_callee_edges #-1
passhook copyrename #26
passhook ccp #27
passhook forwprop #28
```

etc etc . . .

ex.4 Searching function by matching

Goal:

Find all (definitions of) functions with

1. their name starting with `bee`
2. all the formal arguments being integral types (e.g. `int` or `long`, but not pointers or structures)

Showing:

- usage of "ad-hoc" **iterative constructs** (specific to Gcc)
- filtering thru **pattern matching**
- emission of informational messages to the user

using interative constructs in Melt

Assume we have the `:tree` of some function declaration in `cfundecl`. To iterate on all the formal parameters of that declared function, we code:

```
(each_param_in_fundecl
   (cfundecl)
   (:tree argdtree)
   ⌈do something with argdtree (next slide)⌋
)
```

We give a sequence of input arguments - here `(cfundecl)` - and a sequence of local formals - here `(:tree argdtree)` - to the **c-iterator** `each_param_in_fundecl`.

A c-iterator is defined with macro-strings to expand it into *C*. Melt has a lot of iterative constructs, because Gcc provides many of them.

filtering trees with pattern-matching

We look for tree (in `argdtree`) which declares a parameter, whose type is an integer type, using **pattern matching** with several *matching clauses*:

```
(match argtree
  ( ?(tree_parm_decl
       ?(tree_integer_type ?typename ?_ ?_ ?_)
       ?paramname)
    (debug "found integral parameter typename=" typename
           " of paramname=" paramname)
    (void) ;; a "no-op" of c-type :void
  )
  ( ?_
    (setq ok 0)) ;; assign to ok the raw long stuff 0
)
```

A **matching clause** starts with a pattern, then a body of sub-expressions. A **pattern** is a syntactic category (not an expression). It is often **nested**, with **sub-patterns**. Pattern variables (e.g. **`?paramname`**) are bound only in their matching clause. **?_** is the **joker** or **wildcard** pattern.

matching the current function's declaration

```
;; our execute function in pass
(defun searchfun_pass_exec  ()
  (with_cfun_decl   ()
   (:tree cfundecl)
   (debug "searchfun_exec cfundecl=" cfundecl)
   (match cfundecl
      ( ?(tree_function_decl_named
          ?(cstring_prefixed "bee") ?_)
         (let ( (:long ok 1)
                )
           ⌈check that cfundecl has only integral parameters with each_param_in_fundecl ...⌋
           (if ok
               (inform_at_tree cfundecl "found nice beefy function"))))
      ( ?_
         (void)))
```

with_cfun_decl is also an interator. We display the informative message only when `ok` has not been cleared with **setq**.

Contents

Code size of GCC

Released `gcc-4.6.0.tar.gz` (on march 25^{th}, 2011) is 92206220 bytes (90Mb).
The gunzip-ed tar-ball `gcc-4.6.0.tar` is 405Mb.
Previous `gcc-4.5.0.tar.gz` (released on april 14^{th}, 2010)[13] was 82Mb.

`gcc-4.6.0/` measured with D.Wheeler's SLOCcount:
4,296,480 Physical Source Lines of Code

Measured with `ohcount -s`, in total:

- 57360 source files
- 5477333 source code lines
- 1689316 source comment lines
- 1204008 source blank lines
- 8370657 source total lines

[13] There have been minor releases up to `gcc-4.5.3` in april 29^{th}, 2011.

Why is GCC so complex?

- it **accepts many source languages** (C, C++, Ada, Fortran, Go, Objective-C, Java, ...), so has many front-ends
- it **targets** several **dozens of processors** thru many back-ends
  - common processors like x86 (ia-32), x86-64 (AMD64), ARM, PowerPC (32 & 64 bits), Sparc (32 & 64 bits) ...
  - less common processors: ia-64 (Itanium), IBM Z/390 mainframes, PA-RISC, ETRAX CRIS, MC68000 & DragonBall & ColdFire, ...
  - extinct or virtual processors: PDP-11, VAX, MMIX, ...
  - processors supported by external variants: M6809, PIC, Z8000 ...
- it **runs on many operating systems**, perhaps with **cross-compilation**
- it performs **many optimizations** (mostly target **neutral**!)
- because **today's processors are complex**, and **far from C**
- so Gcc has an **extensive test-suite**

Why GCC needs to be complex?

See the **Essential Abstractions in GCC** tutorial at CGO2011 `http://www.cse.iitb.ac.in/grc/index.php?page=gcc-tut` by Uday Khedker (India Institute of Technology, Bombay)

Because Gcc is not only the **Gnu Compiler Collection**, but is now a **compilation framework** so becomes the **Great Compiler Challenge**
Since current processors are big chips (10^9 transistors), their micro-architecture is complex (and GCC has to work a lot for them):

- GHz clock rate
- many functional units working in parallel
- massive L1, L2, L3 caches (access to RAM is very slow, ≈ 1000 cycles)
- out-of-order execution
- branch prediction

Today's x86 processors (AMD Bulldozer, Intel Sandy Bridge) are not like i486 (1990, at 50MHz) running much faster, even if they nearly share the same ia-32 instruction set (in 32 bits mode). Gcc needs to optimize differently for AMD than for Intel!

Why is understanding GCC difficult?

- "**Gcc is** not a compiler but **a compiler generation framework**": (U.Khedker)
  - **a lot of C code** inside Gcc **is generated** at building time.
  - Gcc has many **ad-hoc code generators**
    (some are simple `awk` scripts, others are big tools coded in many KLOC-s of C)
  - Gcc has **several** ad-hoc **formalisms** (perhaps call them *domain specific languages*)
- Gcc is growing gradually and does have some legacy (but powerful) code
- Gcc has no single architect ("benevolent dictator"):
  (no "Linus Torvalds" equivalent for Gcc)
- **Gcc source code is heterogenous**:
  - coded in various programming languages (C, C++, Ada . . .)
  - coded at very different times, by many people (with various levels of expertise).
  - no unified naming conventions
  - *(my opinion only:)* still weak infrastructure (but powerful)
  - not enough common habits or rules about: memory management, pass roles, debug help, comments, dump files . . .
- Gcc code is sometimes quite messy (e.g. compared to Gtk).

What you should read on GCC

You should (find lots of resources on the Web, then) read:

- the Gcc user documentation http://gcc.gnu.org/onlinedocs/gcc/, giving:
  - how to invoke `gcc` (all the obscure optimization flags)
  - various language (C, C++) extensions, including attributes and builtins.
  - how to contribute to Gcc and to report bugs
- the **Gcc internal documentation** http://gcc.gnu.org/onlinedocs/gccint/, explaining:
  - the overall structure of Gcc and its pass management
  - major (but not all) internal representations (notably Tree, Gimple, RTL . . .).
  - memory management, `GTY` annotations, `gengtype` generator
  - interface available to plugins
  - machine and target descriptions
  - LTO internals
- the source code, mostly **header files** `*.h`, **definition files** `*.def`, option files `*.opt`. Don't be lost in Gcc monster source code.[14]

[14] You probably should avoid reading many `*.c` code files at first.

utilities and infrastructure

`gcc` is only a driver (file `gcc/gcc.c`). Most things happen in `cc1`. See file `gcc/toplev.c` for the `toplev_main` function starting `cc1` and others.

There are **many infrastructures and utilities** in Gcc

1. `libiberty/` to abstract system dependencies
2. the **Gcc Garbage Collector** i.e. Ggc:
   - a naive precise mark-and sweep garbage collector
   - sadly, not always used (many routines handle data manually, with explicit `free`)
   - runs only between passes, so used **for data shared between passes**
   - **don't handle any local variables** ☹
   - about 1800 `struct` inside Gcc are annotated with **`GTY` annotations**.
   - the **gengtype** generator produces marking routines in C out of `GTY`

   I love the idea of a garbage collector (but others don't).
   I think Ggc should be better, and be more used.
3. diagnostic utilities
4. preprocessor library `libcpp/`
5. many hooks (e.g. language hooks to factorize code between C, C++, ObjectiveC)

cc1 front-end

The front-end (see function `compile_file` in `gcc/toplev.c`) is reading the input files of a translation unit (e.g. a `foo.c` file and all `#include`-d `*.h` files).

- **language specific hooks** are given thru `lang_hooks` global variable, in `$GCCSOURCE/gcc/langhooks.h`
- `$GCCSOURCE/libcpp/` is a common **library** (for C, C++, Objective C...) **for** lexing and **preprocessing**.
- C-like front-end processing happens under `$GCCSOURCE/gcc/c-family/`
- **parsing** happens in `$GCCSOURCE/gcc/c-parser.c` and `$GCCSOURCE/gcc/c-decl.c`, **using manual recursive descent parsing techniques**[15] to help syntax error diagnostics.
- abstract syntax **Tree**-s [AST] (and **Generic** to several front-ends)

In `gcc-4.6` **plugins cannot enhance the parsed language**
(except thru events for `#pragma`-s or `__attribute__` etc ...)

[15] Gcc don't use LALR parser generators like yacc or bison for C.

GCC middle-end

The middle-end is the most important[16] (and bigger) **part** of Gcc

- it is mostly **independent of** both the **source language** and of the **target machine** (of course, `sizeof(int)` matters in it)
- it **factorizes all the optimizations** reusable for various sources languages or target systems
- it processes (i.e. transforms and enhances) several **middle-end internal** (and interleaved) **representations**, notably
  1. declarations and operands represented by **Tree**-s
  2. **Gimple** representations ("3 address-like" instructions)
  3. Control Flow Graph informations (**Edges**, **Basic Blocks**, ...)
  4. Data dependencies
  5. **Static Single Assignment** (SSA) variant of **Gimple**
  6. many others

I [Basile] am more familiar with the middle-end than with front-ends or back-ends.

[16] Important to me, since I am a middle-end guy!

Middle End and Link Time Optimization

With LTO, the middle-end representations are both input and output.

- LTO enables optimization across several compilation units, e.g. inlining of a function defined in `foo.cc` and called in `bar.c`
  (LTO existed in old proprietary compilers, and in LLVM)
- when compiling source translation units in LTO mode, the generated object `*.o` file contains both:
  - (as always) binary code, relocation directives (to the linker), debug information (for `gdb`)
  - (for LTO) **summaries**, a simplified serialized form of middle-end representations
- when “linking” these object files in LTO mode, `lto1` is a “front-end” to this middle-end data contained in `*.o` files. The program `lto1` is started by the `gcc` driver (like `cc1plus ...`)
- in **WHOPR** mode (whole program optimization), LTO is split in three stages (LGEN = local generation, in parallel; sequential WPA = whole program analysis; LTRANS = local transformation, in parallel).

GCC back-ends

The **back-end**[17] is the last layer of Gcc (specific to the target machine):

- it contains all **optimizations** (etc ...) **particular to its target system** (notably peepwhole target-specific optimizations).
- it **schedules** (machine) **instructions**
- it **allocates registers**[18]
- it emits assembler code (and follows target system conventions)
- it transforms *gimple* (given by middle-end) into back-end representations, notably **RTL** (register transfer language)
- it optimizes the RTL representations
- some of the back-end C code is **generated** by **machine descriptions** `*.md` files.

☹ **I** [Basile] **don't know much about back-ends**

---

[17] A given `cc1` or `lto1` has usually one back-end (except multilib ie `-m32` vs `-m64` on `x86-64`). But Gcc source release has many back-ends!

[18] Register allocation is a very hard art. It has been rewritten many times in Gcc.

“meta-programming” C code generators in GCC

Gcc has several internal C code generators (built in `$GCCBUILD/gcc/build/`):

- **gengtype** for Ggc, generating marking code from `GTY` annotations
- **genhooks** for target hooks, generating `target-hooks-def.h` from `target.def`
- **genattrtab**, **genattr**, **gencodes**, **genconditions**, **gencondmd**, **genconstants**, **genemit**, **genenums**, **genextract**, **genflags**, **genopinit**, **genoutput**, **genpreds**, to generate machine attributes and code from machine description `*.md` files.
- **genautomata** to generate pipeline hazard automaton for instruction scheduling from `*.md`
- **genpeep** to generate peephole optimizations from `*.md`
- **genrecog** to generate code recognizing RTL from `*.md`
- etc ...

(`genautomata`, `gengtype`, `genattrtab` are quite big generators)

GCC pass manager and passes

The **pass manager** is coded in `$GCCSOURCE/gcc/passes.c` and `tree-optimize.c` with `tree-pass.h`

There are many (≈ 250) passes in Gcc:
The set of executed passes depend upon optimization flags (`-O1` vs `-O3` ...) and of the translation unit.

- middle-end passes process *Gimple* (and other representations)
  - **simple *Gimple* passes** handle Gimple code one function at a time.
  - simple and full **IPA *Gimple* passes** do **Inter-Procedural Analysis** optimizations.
- back-end passes handle *RTL* etc ...

Passes are organized in a tree. A pass may have sub-passes, and could be run several times.

Both middle-end and back-end passes go into `libbackend.a`!

Plugins can add (or remove, or monitor) passes.

Garbage Collection inside GCC

Ggc is implemented in `$GCCSOURCE/gcc/ggc*.[ch]`[19] and thru the **gengtype** generator `$GCCSOURCE/gcc/gengtype*.[chl]`.

- the **`GTY`** annotation (on `struct` and **global or static data**) is used to "declare" Ggc handled data and types.
- `gengtype` generates marking and allocating routines in `gt-*.h` and `gtyp*.[ch]` files (in `$GCCBUILD/gcc/`)
- **`ggc_collect ();`** calls Ggc; it is mostly called by the pass manager.
- ☹ **local pointers** (variables inside Gcc functions) are **not preserved** by Ggc so `ggc_collect` can't be called[20] everywhere!
- ⇒ passes have to copy (pointers to their data) to static `GTY`-ed variables
- so Ggc is unfortunately not systematically used
  (often data local to a pass is manually managed & explicitly freed)

[19] `ggc-zone.c` is often unused.

[20] Be very careful if you need to call `ggc_collect` yourself *inside* your pass!

Why real compilers need garbage collection?

- compilers have complex internal representations ($\approx$ 1800 `GTY`-ed types!)
- compilers are become very big and complex programs
- it is difficult to decide when a compiler data can be (manually) freed
- **circular data structures** (e.g. back-pointers from Gimple to containing Basic Blocks) are common inside compilers; compiler data are not (only) tree-like.
- **liveness** of a data is a **global** (non-modular) property!
- garbage collection techniques are mature
  (garbage collection is a global trait in a program)
- memory is quite cheap

In my (strong) opinion, **Ggc** is not very good[21] -but cannot and shouldn't be avoided-, and **should systematically be used**, so improved.
Even today, some people manually sadly manage their data in their pass.

[21] Chicken & egg issue here: Ggc not good enough ⇒ not very used ⇒ not improved!

using Ggc in your C code for Gcc

Annotate your `struct` declarations with **GTY** in your C code:

```
 // from $GCCSOURCE/gcc/tree.h
struct GTY ((chain_next ("%h.next"), chain_prev ("%h.prev")))
       tree_statement_list_node {
  struct tree_statement_list_node *prev;
  struct tree_statement_list_node *next;
  tree stmt;         // The tree-s are GTY-ed pointers
};

struct GTY(()) tree_statement_list {
  struct tree_typed typed;
  struct tree_statement_list_node *head;
  struct tree_statement_list_node *tail;
};
```

Likewise for global or static variables:

```
extern GTY(()) VEC(alias_pair,gc) * alias_pairs;
```

Notice the poor man's vector "template" thru the **VEC** "mega"-macro (from `$GCCSOURCE/gcc/vec.h`) known by `gengtype`

GTY annotations

http://gcc.gnu.org/onlinedocs/gccint/Type-Information.html

Often empty, these annotations help to generate good marking routines:

- `skip` to ignore a field
- list chaining with `chain_next` and `chain_previous`
- [variable-] array length with `length` and `variable_size`
- discriminated unions with `descr` and `tag` . . .
- poor man's genericity with `param2_is` or `use_params` etc . . .
- marking hook routine with `mark_hook`
- etc . . .

From `tree.h` **gengtype** is generating `gt-tree.h` which is `#include`-d from `tree.c`

Pre Compiled Headers (PCH)[22] also use **gengtype** & **GTY**.

[22] PCH is a feature which might be replaced by "pre-parsed headers" in the future.

Example of **gengtype** generated code

Marking routine:

// in $GCCBUILD/gcc/gtype-desc.c

```
void gt_ggc_mx_tree_statement_list_node (void *x_p) {
  struct tree_statement_list_node * x = (struct tree_statement_list_node *)x_p;
  struct tree_statement_list_node * xlimit = x;
  while (ggc_test_and_set_mark (xlimit))
   xlimit = ((*xlimit).next);
  if (x != xlimit)
    for (;;) {
        struct tree_statement_list_node * const xprev = ((*x).prev);
        if (xprev == NULL) break;
        x = xprev;
        (void) ggc_test_and_set_mark (xprev);
      }
  while (x != xlimit)  {
      gt_ggc_m_24tree_statement_list_node ((*x).prev);
      gt_ggc_m_24tree_statement_list_node ((*x).next);
      gt_ggc_m_9tree_node ((*x).stmt);
      x = ((*x).next);
    } }
```

Allocators:

// in $GCCBUILD/gcc/gtype-desc.h

```
#define ggc_alloc_tree_statement_list() \
  ((struct tree_statement_list *)(ggc_internal_alloc_stat (sizeof (struct tree_statement_list) ME
#define ggc_alloc_cleared_tree_statement_list() \
  ((struct tree_statement_list *)(ggc_internal_cleared_alloc_stat (sizeof (struct tree_statement_
#define ggc_alloc_vec_tree_statement_list(n) \
   ((struct tree_statement_list *)(ggc_internal_vec_alloc_stat (sizeof (struct tree_statement_lis
```

Ggc work

The Ggc garbage collector is a mark and sweep precise collector, so:

- each Ggc-aware memory zone has some kind of mark
- first Ggc clears all the marks
- then Ggc marks all the [global or static] roots[23], and "recursively" marks all the (still unmarked) data accessible from them, using routines generated by **gengtype**
- at last Ggc frees all the unmarked memory zones

Complexity of Ggc is $\approx O(m)$ where m is the **total memory size**.

When not much memory has been allocated, `ggc_collect` returns immediately and don't really run Ggc[24]

Similar trick for pre-compiled headers: compiling a `*.h` file means parsing it and persisting all the roots (& data accessible from them) into a compiled header.

[23] That is, `extern` or `static` ***GTY***-ed variables.

[24] Thanks to `ggc_force_collect` internal flag.

allocating GTY-ed data in your C code

gengtype also generates allocating macros named `ggc_alloc*`. Use them like you would use `malloc` ...

```
// from function tsi_link_before in $GCCSOURCE/gcc/tree-iterator.c
  struct tree_statement_list_node *head, *tail;
  // ...
  {
      head = ggc_alloc_tree_statement_list_node ();
      head->prev = NULL;  head->next = NULL;  head->stmt = t;
      tail = head;
  }
```

Of course, ☺ you **don't** need to **free that memory**: Ggc will do it for you.
GTY-ed allocation never starts automatically a Ggc collection[25], and has some little cost. Big data can be `GTY`-allocated. Variable-sized data allocation macros get as argument the total size (in bytes) to be allocated.

Often we wrap the allocation inside small inlined "constructor"-like functions.

[25] Like almost every other garbage collector would do; Ggc can't behave like that because it ignores local pointers, but most other GCs handle them!

Pass descriptors

Middle-end and back-end passes are described in structures defined in **$GCCSOURCE/gcc/tree-pass.h**. They all are `opt_pass`-es with:

- some **type**, either `GIMPLE_PASS`, `SIMPLE_IPA_PASS`, `IPA_PASS`, or `RTL_PASS`
- some human readable **name**. If it starts with * no dump can happen.
- an optional **gate** function "hook", deciding if the pass (and its optional sub-passes) should run.
- an **execute** function "hook", doing the actual work of the pass.
- required, provided, or destroyed **properties** of the pass.
- **"to do" flags**
- other fields used by the pass manager to organize them.
- timing identifier `tv_id` (for `-freport-time` program option).

Full IPA passes have more descriptive fields (related to LTO serialization).

Most of file `tree-pass.h` declare pass descriptors, e.g.:

```
extern struct gimple_opt_pass pass_early_ipa_sra;
extern struct gimple_opt_pass pass_tail_recursion;
extern struct gimple_opt_pass pass_tail_calls;
```

A pass descriptor [control flow graph building]

In file `$GCCSOURCE/gcc/tree-cfg.c`

```
struct gimple_opt_pass pass_build_cfg = { {
  GIMPLE_PASS,
  "cfg",                               /* name */
  NULL,                                /* gate */
  execute_build_cfg,                   /* execute */
  NULL,                                /* sub */
  NULL,                                /* next */
  0,                                   /* static_pass_number */
  TV_TREE_CFG,                         /* tv_id */
  PROP_gimple_leh,                     /* properties_required */
  PROP_cfg,                            /* properties_provided */
  0,                                   /* properties_destroyed */
  0,                                   /* todo_flags_start */
  TODO_verify_stmts | TODO_cleanup_cfg
  | TODO_dump_func                     /* todo_flags_finish */
 } };
```

Another pass descriptor [tail calls processing]

```
struct gimple_opt_pass pass_tail_calls = { {
  GIMPLE_PASS,
  "tailc",                              /* name */
  gate_tail_calls,                      /* gate */
  execute_tail_calls,                   /* execute */
  NULL,                                 /* sub */
  NULL,                                 /* next */
  0,                                    /* static_pass_number */
  TV_NONE,                              /* tv_id */
  PROP_cfg | PROP_ssa,                  /* properties_required */
  0,                                    /* properties_provided */
  0,                                    /* properties_destroyed */
  0,                                    /* todo_flags_start */
  TODO_dump_func | TODO_verify_ssa      /* todo_flags_finish */ } };
```

This file `$GCCSOURCES/gcc/tree-tailcall.c` contains two related passes, for tail recursion elimination.
Notice that the human `name` (here `"tailc"`) is unfortunately unlike the C identifier `pass_tail_calls` (so finding a pass by its `name` can be boring).

IPA pass descriptor: interprocedural constant propagation

```
struct ipa_opt_pass_d pass_ipa_cp = { { // in file $GCCSOURCE/gcc/ipa-cp.c
  IPA_PASS,
  "cp",                            /* name */
  cgraph_gate_cp,                  /* gate */
  ipcp_driver,                     /* execute */
  NULL,                            /* sub */
  NULL,                            /* next */
  0,                               /* static_pass_number */
  TV_IPA_CONSTANT_PROP,            /* tv_id */
  0,                               /* properties_required */
  0,                               /* properties_provided */
  0,                               /* properties_destroyed */
  0,                               /* todo_flags_start */
  TODO_dump_cgraph | TODO_dump_func |
  TODO_remove_functions | TODO_ggc_collect /* todo_flags_finish */
 },
 ipcp_generate_summary,                   /* generate_summary routine for LTO */
 ipcp_write_summary,                      /* write_summary routine for LTO */
 ipcp_read_summary,                       /* read_summary routine for LTO */
 NULL,                                    /* write_optimization_summary */
 NULL,                                    /* read_optimization_summary */
 NULL,                                    /* stmt_fixup */
 0,                                       /* TODOs */
 NULL,                                    /* function_transform */
 NULL,                                    /* variable_transform */
};
```

RTL pass descriptor: dead-store elimination

```
struct rtl_opt_pass pass_rtl_dse1 = { {  // in file $GCCSOURCE/gcc/dse.c
  RTL_PASS,
  "dse1",                                 /* name */
  gate_dse1,                              /* gate */
  rest_of_handle_dse,                     /* execute */
  NULL,                                   /* sub */
  NULL,                                   /* next */
  0,                                      /* static_pass_number */
  TV_DSE1,                                /* tv_id */
  0,                                      /* properties_required */
  0,                                      /* properties_provided */
  0,                                      /* properties_destroyed */
  0,                                      /* todo_flags_start */
  TODO_dump_func |
  TODO_df_finish | TODO_verify_rtl_sharing |
  TODO_ggc_collect                        /* todo_flags_finish */
 } };
```

There is a similar `pass_rtl_dse2` in the same file.

How the pass manager is activated?

Language specific `lang_hooks.parse_file` (e.g. `c_parse_file` in `$GCCSOURCES/gcc/`**`c-parser.c`** for ***cc1***) is called from `compile_file` in `$GCCSOURCES/gcc/toplev.c`.

When a C function has been entirely parsed by the front-end, `finish_function` (from `$GCCSOURCE/gcc/c-decl.c`) is called. Then

1. `c_genericize` in `$GCCSOURCE/gcc/c-family/c-gimplify.c` is called. The C-specific abstract syntax tree (AST) is transformed in **Generic** representations (common to several languages);
2. several functions from `$GCCSOURCE/gcc/gimplify.c` are called: `gimplify_function_tree` → `gimplify_body` → `gimplify_stmt` → `gimplify_expr`
3. some language-specific gimplification happens thru `lang_hooks.gimplify_expr`, e.g. `c_gimplify_expr` for ***cc1***.
4. etc . . .

Then `tree_rest_of_compilation` (in file `$GCCSOURCE/gcc/tree-optimize.c`) is called.

Pass registration

Passes are **registered** within the pass manager. Plugins indirectly call `register_pass` thru the **`PLUGIN_PASS_MANAGER_SETUP`** event.

Most Gcc core passes are often statically registered, thru lot of code in **`init_optimization_passes`** like

```
  struct opt_pass **p;
#define NEXT_PASS(PASS) (p = next_pass_1 (p, &((PASS).pass)))
  p = &all_lowering_passes;
  NEXT_PASS (pass_warn_unused_result);
  NEXT_PASS (pass_diagnose_omp_blocks);  NEXT_PASS (pass_mudflap_1);
  NEXT_PASS (pass_lower_omp);  NEXT_PASS (pass_lower_cf);
  NEXT_PASS (pass_refactor_eh);  NEXT_PASS (pass_lower_eh);
  NEXT_PASS (pass_build_cfg);  NEXT_PASS (pass_warn_function_return);
// etc ...
```

`next_pass_1` calls **`make_pass_instance`** which clones a pass. Passes may be dynamically duplicated.

Passes are organized in a **hierarchical tree of passes**. Some passes have sub-passes (which run only if the super-pass `gate` function succeeded).

Running the pass manager

Function `tree_rest_of_compilation` calls `execute_all_ipa_transforms` and most importantly **`execute_pass_list`** `(all_passes)` (file `$GCCSOURCE/gcc/passes.c`)
The role of the pass manager is to run passes using **`execute_pass_list`** thru **`execute_one_pass`**.
Some passes have sub-passes ⇒ `execute_pass_list` is recursive.
It has specific variants:
(e.g. `execute_ipa_pass_list` or `execute_all_ipa_transforms`, etc...)
Each pass has an **`execute`** function, returning a set of **to do flags**, merged with the `todo_finish` flags in the pass.

To Do actions are processed by **`execute_todo`**, with code like

```
if (flags & TODO_ggc_collect)
  ggc_collect ();
```

Issues when defining your pass

☺ The **easy** parts:

- **define what your pass should do**
- specify your `gate` function, if relevant
- specify your `exec` function
- define the **properties** and **to-do** flags

☹ The **difficult** items:

- **position your new pass** within the existing passes
  ⇒ understand after which pass should you add yours!
- understand **what internal representations are really available**
- understand **what next passes expect**!
- ⇒ understand **which passes are running**?

I [Basile] also have these difficulties !!

pass dump

Usage: pass **-fdump-*-*** program flags[26] to gcc

- Each pass can **dump** information **into textual files**.
  ⇒ your new passes should provide dumps.[27]
- ⇒ So you could get **hundreds of dump files**:
  hello.c → hello.c.000i.cgraph hello.c.224t.statistics
  (but the **numbering** don't means much ☹, they are **not chronological**!)
- try **-fdump-tree-all -fdump-ipa-all -fdump-rtl-all**
- you can choose your dumps:
  - **-fdump-tree-**π to dump the tree or GIMPLE_PASS named π
  - **-fdump-ipa-**π to dump the i.p.a. SIMPLE_IPA_PASS or IPA_PASS named π
  - **-fdump-rtl-**π to dump the r.t.l. RTL_PASS named π
- **dump files don't contain all the information**
  (and there is no way to parse them) [28].

[26] Next gcc-4.7 will have improved [before/after] flags

[27] Unless the pass name starts with $\star$.

[28] Some Gcc gurus dream of a fully accurate and reparsable textual representation of *Gimple*

Dump example: input source `example1.c`

(using `gcc-melt`[29] svn rev. 174968 ≡ `gcc-trunk` svn rev. 174941, of june 11th 2011)

```c
/* example1.c */
extern int gex(int);

int foo(int x, int y) {
  if (x>y)
    return gex(x-y) * gex(x+y);
  else
    return foo(y,x);
}

void bar(int n, int *t) {
  int i;
  for (i=0; i<n; i++)
    t[i] = foo(t[i], i) + i;
}
```

[29] The Melt **branch** (not the plugin) is dumping into *chronologically named* files, e.g. `example1.c.%0026.017t.ssa`!

Dump gimplification `example1.c.004t.gimple`

```
bar (int n, int * t)  {
  long unsigned int D.2698;
  long unsigned int D.2699;
  int * D.2700;
  int D.2701; int D.2702; int D.2703;
  int i;
  i = 0;
  goto <D.1597>;
  <D.1596>:
  D.2698 = (long unsigned int) i;
  D.2699 = D.2698 * 4;
  D.2700 = t + D.2699;
  D.2698 = (long unsigned int) i;
  D.2699 = D.2698 * 4;
  D.2700 = t + D.2699;
  D.2701 = *D.2700;
  D.2702 = foo (D.2701, i);
  D.2703 = D.2702 + i;
  *D.2700 = D.2703;
  i = i + 1;
  <D.1597>:
  if (i < n) goto <D.1596>;
  else goto <D.1598>;
  <D.1598>:   }

foo (int x, int y) {
  int D.2706;  int D.2707;  int D.2708;
  int D.2709; int D.2710;
  if (x > y) goto <D.2704>;
  else goto <D.2705>;
  <D.2704>:
  D.2707 = x - y;
  D.2708 = gex (D.2707);
  D.2709 = x + y;
  D.2710 = gex (D.2709);
  D.2706 = D.2708 * D.2710;
  return D.2706;
  <D.2705>:
  D.2706 = foo (y, x);
  return D.2706;    }
```

functions in reverse order; 3 operands instructions; generated temporaries; generated **goto**-s

Dump SSA - [part of] `example1.c.017t.ssa`

only the `foo` function of that dump file, in **Static Single Assignment SSA** form

```
;; Function foo
(foo, funcdef_no=0, decl_uid=1589,
      cgraph_uid=0)
Symbols to be put in SSA form { .MEM }
Incremental SSA update started at block: 0
Number of blocks in CFG: 6
Number of blocks to update: 5 ( 83%)

foo (int x, int y) {
  int D.2710;  int D.2709;
  int D.2708;  int D.2707;  int D.2706;

<bb 2>:
  if (x_2(D) > y_3(D))
    goto <bb 3>;
  else goto <bb 4>;

<bb 3>:
  D.2707_4 = x_2(D) - y_3(D);
  D.2708_5 = gex (D.2707_4);
  D.2709_6 = x_2(D) + y_3(D);
  D.2710_7 = gex (D.2709_6);
  D.2706_8 = D.2708_5 * D.2710_7;
  goto <bb 5>;

<bb 4>:
  D.2706_9 = foo (y_3(D), x_2(D));

<bb 5>:
  # D.2706_1 = Φ <D.2706_8(3), D.2706_9(4)>
  return D.2706_1;    }
```

SSA ⇔ each variable is assigned once; suffix `(D)` for default definitions of SSA names

e.g $D.2707_4$ [appearing as `D.2707_4` in dump files]

Basic blocks: only entered at their start

ϕ-nodes; "union" of values coming from two edges

IPA dump - [tail of] example1.c.049i.inline

```
;; Function bar (bar, funcdef_no=1,
        decl_uid=1593, cgraph_uid=1)
bar (int n, int * t) {
  int i;
  int D.2703;  int D.2702;  int D.2701;
  int * D.2700;
  long unsigned int D.2699;
  long unsigned int D.2698;

  # BLOCK 2 freq:900
  # PRED: ENTRY [100.0%]  (fallthru,exec)
  goto <bb 4>;
  # SUCC: 4 [100.0%]  (fallthru,exec)

  # BLOCK 3 freq:9100
  # PRED: 4 [91.0%]  (true,exec)
  D.2698_8 = (long unsigned int) i_1;
  D.2699_9 = D.2698_8 * 4; /// 4 ≡ sizeof(int)
  D.2700_10 = t_6(D) + D.2699_9;
  D.2701_11 = *D.2700_10;
  D.2702_12 = foo (D.2701_11, i_1);
  D.2703_13 = D.2702_12 + i_1;
  *D.2700_10 = D.2703_13;
  i_14 = i_1 + 1;
  # SUCC: 4 [100.0%]
          (fallthru,dfs_back,exec)

  # BLOCK 4 freq:10000
  # PRED: 2 [100.0%]
          (fallthru,exec) 3 [100.0%]
          (fallthru,dfs_back,exec)
  # i_1 = PHI <0(2), i_14(3)>
  if (i_1 < n_3(D))
    goto <bb 3>;
  else goto <bb 5>;
  # SUCC: 3 [91.0%]  (true,exec) 5 [9.0%]

  # BLOCK 5 freq:900
  # PRED: 4 [9.0%]  (false,exec)
  return;
  # SUCC: EXIT [100.0%]
}
```

The call to `foo` has been inlined; edges of CFG have frequencies

RTL dump [small part of] example1.c.162r.reginfo

```
;; Function bar (bar, funcdef_no=1, decl_uid=1593,
          cgraph_uid=1)
verify found no changes in insn with uid = 31.
(note 21 0 17 2 [bb 2] NOTE_INSN_BASIC_BLOCK)
(insn 17 21 18 2 (set (reg/v:SI 84 [ n ])
        (reg:SI 5 di [ n ]))
            example1.c:11 64 {*movsi_internal}
     (expr_list:REG_DEAD (reg:SI 5 di [ n ])
        (nil)))
(insn 18 17 19 2 (set (reg/v/f:DI 85 [ t ])
        (reg:DI 4 si [ t ]))
         example1.c:11 62 {*movdi_internal_rex64}
     (expr_list:REG_DEAD (reg:DI 4 si [ t ])
        (nil)))
(note 19 18 23 2 NOTE_INSN_FUNCTION_BEG)
(insn 23 19 24 2 (set (reg:CCNO 17 flags)
        (compare:CCNO (reg/v:SI 84 [ n ])
            (const_int 0 [0])))
            example1.c:13 2 {*cmpsi_ccno_1}
     (nil))
(jump_insn 24 23 25 2 (set (pc)
        (if_then_else (le (reg:CCNO 17 flags)
                (const_int 0 [0]))
            (label_ref:DI 42)
            (pc))) example1.c:13 594 *jcc_1
     (expr_list:REG_DEAD (reg:CCNO 17 flags)
        (expr_list:REG_BR_PROB (const_int 900 [0x
            (nil)))
 -> 42)
(note 25 24 26 3 [bb 3] NOTE_INSN_BASIC_BLOCK)
(insn 26 25 20 3 (set (reg:DI 82 [ ivtmp.14 ])
        (reg/v/f:DI 85 [ t ])) 62 {*movdi_interna
     (expr_list:REG_DEAD (reg/v/f:DI 85 [ t ])
        (nil)))
(insn 20 26 37 3 (set (reg/v:SI 78 [ i ])
        (const_int 0 [0])) example1.c:13 64
        {*movsi_internal}
     (nil))
(code_label 37 20 27 4 9 "" [1 uses])
(note 27 37 29 4 [bb 4] NOTE_INSN_BASIC_BLOCK)
(insn 29 27 30 4 (set (reg:SI 4 si)
        (reg/v:SI 78 [ i ])) example1.c:14 64 {*m
     (nil))
(insn 30 29 31 4 (set (reg:SI 5 di)
        (mem:SI (reg:DI 82 [ ivtmp.14 ])
          [2 MEM[base: D.2731_28, offset: 0B]+0 S
                example1.c:14 64 {*movsi_interna
     (nil))
```

/// etc...

I [Basile] can't explain it ☹; but notice x86 specific code

generated assembly [part of] `example1.s`

```
        .file   "example1.c"

# options enabled:  -fasynchronous-unwind-tables
# -fauto-inc-dec
## etc etc etc ...
# -fverbose-asm -fzee -fzero-initialized-in-bss
# -m128bit-long-double -m64 -m80387
# -maccumulate-outgoing-args -malign-stringops
# -mfancy-math-387 mfp-ret-in-387 -mglibc
# -mieee-fp -mmmx -mno-sse4 -mpush-args
#  -mred-zone msse  -msse2 -mtls-direct-seg-refs

        .globl  bar
        .type   bar, @function
bar:
.LFB1:
        .cfi_startproc
        pushq   %r12    #
        .cfi_def_cfa_offset 16
        .cfi_offset 12, -16
        testl   %edi, %edi      # n
        movl    %edi, %r12d     # n, n
        pushq   %rbp    #
        .cfi_def_cfa_offset 24
        .cfi_offset 6, -24
        pushq   %rbx    #
        .cfi_def_cfa_offset 32
        .cfi_offset 3, -32
        jle     .L7     #,
        movq    %rsi, %rbp      # t, ivtmp.14
        xorl    %ebx, %ebx      # i
        .p2align 4,,10
        .p2align 3
.L9:
        movl    0(%rbp), %edi   # MEM[base: D.273
        movl    %ebx, %esi      # i,
        call    foo     #
        addl    %ebx, %eax      # i, tmp86
        addl    $1, %ebx        #, i
        movl    %eax, 0(%rbp)   # tmp86, MEM[base
        addq    $4, %rbp        #, ivtmp.14
        cmpl    %r12d, %ebx     # n, i
        jne     .L9     #,
.L7:
        popq    %rbx    #
        .cfi_def_cfa_offset 24
        popq    %rbp    #
        .cfi_def_cfa_offset 16
        popq    %r12    #
        .cfi_def_cfa_offset 8
        ret         .cfi_endproc
.LFE1:
        .size   bar, .-bar
        .ident  "GCC: (GNU) 4.7.0 20110611 (exper
                [trunk revision 174943]"
        .section        .note.GNU-stack,"",@progb
```

Order of executed passes; running gimple passes

- When `cc1` **don't get** the `-quiet` program argument, names of executed **IPA** passes are printed.
- Plugins know about executed passes thru `PLUGIN_PASS_EXECUTION` events.
- global variable `current_pass`
- understanding all the executed passes is not very simple

Simple `GIMPLE_PASS`-es are executed one (compiled) function at a time.

- global `cfun` points to the **current function** as a `struct function` from `$GCCSOURCE/gcc/function.h`
- global `current_function_decl` is a `tree`
- `cfun` is `NULL` for non-gimple passes (i.e. `IPA_PASS`-es)

running inter-procedural passes

They obviously work on the whole compilation unit, so run “once”[30].

Using the **cgraph_nodes** global from `$GCCSOURCE/gcc/cgraph.h`, they often do

```
struct cgraph_node *node;
for (node = cgraph_nodes; node; node = node->next) {
    if (!gimple_has_body_p (node->decl)
        || node->clone_of)
      continue;
// do something useful with node
}
```

If `node->decl` is a `FUNCTION_DECL` tree, we can retrieve its body (a sequence of *Gimple*-s) using **`gimple_body`** (from `$GCCSOURCE/gcc/gimple.h`).
However, often that body is not available, because only the control flow graph exist at that point. We can use **`DECL_STRUCT_FUNCTION`** to retrieve a `struct function`, then **`ENTRY_BLOCK_PTR_FOR_FUNCTION`** to get a `basic_block`, etc...

[30] But the pass manager could run again such a pass.

Plugins

- I [Basile] think that: **plugins are a *very important* feature of Gcc**, but
  - most Gcc **developers don't care**
  - some Gcc hackers are against them
  - Gcc has no stable API [yet?], no binary compatibility
    Gcc internals are under-documented
  - plugins are dependent upon the version of Gcc
  - FSF was hard to convince (plugins required changes in licensing)
  - attracting outside developers to make plugins is hard

  please code Gcc plugins or extensions (using Melt)
- There are still [too] **few plugins**:
  TreeHydra (Mozilla), DragonEgg (LLVM), Milepost/Ctuning??, MELT, etc . . .
- **plugins should be** GPL compatible **free software**
  (GCC licence probably forbids to use proprietary Gcc plugins).
- some distributed Gcc compilers have disabled plugins ☹
- plugins might not work
  (e.g. a plugin started from `lto1` can't do front-end things like registering pragmas)

Why code [plugins in C or] Gcc extensions [in MELT]

IMHO:

- Don't code plugins for features which should go in core Gcc
- You can't do everything thru plugins, e.g. a new front-end for a new language.

Gcc extensions (plugins in C, or extensions in MELT) are useful for:

- **research** and prototyping (of new compilation techniques)
- **specific processing of** source **code** (which don't have its place inside Gcc core):
  - coding rules validation (e.g. Misra-C, Embedded C++, DOI178?, ...), including library or software specific rules

    (e.g. every `pthread_mutex_lock` should have its matching `pthread_mutex_unlock` in the same function or block)
  - improved type checking

    (e.g. typing of variadic functions like `g_object_set` in Gtk)
  - specific optimizations - (e.g. `fprintf(stdout,...)` → `printf(...)`)

  Such specific processing don't have its place inside Gcc itself, because it is tied to a particular { domain, corporation, community, software ... }

dreams of Gcc extensions [in MELT]

You could dare coding these as Gcc plugins in plain **C**, but even as Melt extensions it is not easy!

- **Hyper-optimization** extensions i.e. **-O∞** optimization level ☺
  Gcc guidelines require that passes execute in linear time; but some clever optimizations are provided by cubic or exponential algorithms; some particular users could afford them.
- **Clever warnings** and **static analysis**
  - a free competitor to Coverity™
    idea explored in a Google Summer of Code 2011 project by Pierre Vittet, e.g. `https://github.com/Piervit/GMWarn`
  - application specific analysis
    Alexandre Lissy, *Model Checking the Linux Kernel*
- tools support for large free software (Kde?, Gnome?, ...)

Free Software wants[31] you to code Gcc extensions!

[31] Or is it just me ☺?

Running plugins

- Users can run plugins with program options to **gcc** like
  `-fplugin=/path/to/name.so`
  `-fplugin-arg-name-key[=value]`
- With a short option `-fplugin=name` plugins are loaded from a predefined plugin directory[32] as
  `-fplugin=`gcc -print-file-name=plugin`/name.so`
- Several plugins can be loaded in sequence.
- Gcc accept plugins only on ELF systems (e.g. Gnu/Linux) with `dlopen`, provided plugins have been enabled at configuration time.
- the plugin is **dlopen**-ed by **cc1** or `cc1plus` or even `lto1` (caveat: front-end functions are not in `lto1`)

[32] This could be enhanced in next `gcc-4.7` with language-specific subdirectories.

Plugin as used from Gcc core

Details on `gcc.gnu.org/onlinedocs/gccint/`**`Plugins.html`**; see also file `$GCCSOURCE/gcc/gcc-plugin.h` (which gets installed under the plugin directory)

`cc1` (or `lto1`, ...) is initializing plugins quite early (before parsing the compilation unit or running passes). It checks that **`plugin_is_GPL_compatible`** then run the plugin's **`plugin_init`** function (which gets version info, and arguments, etc...)

Inside Gcc, plugins are invoked from several places, e.g. `execute_one_pass` calls

```
invoke_plugin_callbacks (PLUGIN_PASS_EXECUTION, pass);
```

The `PLUGIN_PASS_EXECUTION` is a **plugin event**. Here, the `pass` is the event-specific **gcc data** (for many events, it is `NULL`). There are ≈ 20 events (and more could be dynamically added, e.g. for one plugin to hook other plugins.).

Event registration from plugins

Plugins should register the events they are interested in, usually from their `plugin_init` function, with a callback of type

```
/* The prototype for a plugin callback function.
    gcc_data  - event-specific data provided by GCC
    user_data - plugin-specific data provided by the plug-in.  */
    typedef void (*plugin_callback_func)
                   (void *gcc_data, void *user_data);
```

Plugins register their callback function `callback` of above type `plugin_callback_func` using **register_callback** (from file `$GCCSOURCE/gcc/gcc-plugin.h`), e.g. from `melt-runtime.c`

```
 register_callback (/*name:*/ melt_plugin_name,
                    /*event:*/ PLUGIN_PASS_EXECUTION,
                    /*callback:*/ melt_passexec_callback,
                    /*no user_data:*/ NULL);
```

Adding or replacing passes in a plugin

(you should know where to add your new pass!)

Use `register_callback` with a `struct register_pass_info` data but no callback, e.g. to register `yourpass` *after* the pass named `"cfg"`:

```
struct register_pass_info passinfo;
memset (&passinfo, 0, sizeof (passinfo));
passinfo.pass = (struct opt_pass*) yourpass;
passinfo.reference_pass_name = "cfg";
passinfo.ref_pass_instance_number = -1;
passinfo.pos_op = PASS_POS_INSERT_AFTER;
register_callback (plugin_info->base_name, PLUGIN_PASS_MANAGER_SETUP,
                  /*no callback routine*/ NULL,
                   &passinfo);
```

The `pos_op` could also be `PASS_POS_INSERT_BEFORE` or `PASS_POS_REPLACE`.

Main plugin events

A **non-exhaustive list** (extracted from `$GCCSOURCE/gcc/plugin.def`), with the role of the optional *gcc data*:

1. **PLUGIN_START** (called from `toplev.c`) called before `compile_file`
2. **PLUGIN_FINISH_TYPE**, called from `c-parser.c` with the new type `tree`
3. **PLUGIN_PRE_GENERICIZE** (from `c-parser.c`) to see the low level AST in C or C++ front-end, with the new function `tree`
4. **PLUGIN_GGC_START** or **PLUGIN_GGC_END** called by Ggc
5. **PLUGIN_ATTRIBUTES** (from `attribs.c`) or **PLUGIN_PRAGMAS** (from `c-family/c-pragma.c`) to register additional attributes or pragmas from front-end.
6. **PLUGIN_FINISH_UNIT** (called from `toplev.c`) can be used for LTO summaries
7. **PLUGIN_FINISH** (called from `toplev.c`) to signal the end of compilation
8. **PLUGIN_ALL_PASSES_{START,END}**, **PLUGIN_ALL_IPA_PASSES_{START,END}**, **PLUGIN_EARLY_GIMPLE_PASSES_{START,END}** are related to passes
9. **PLUGIN_PASS_EXECUTION** identify the given `pass`, and **PLUGIN_OVERRIDE_GATE** (with `&gate_status`) may override gate decisions

Contents

Motivations for MELT

Gcc extensions address a limited number of users[33], so their development should be facilitated (cost-effectiveness issues)

- extensions should be [meta-] plugins, not Gcc variants [branches, forks] [34] which are never used
  ⇒ **extensions** delivered for and **compatible with Gcc releases**
- when understanding Gcc internals, coding plugins in plain **C** is very hard (because C is a system-programming low-level language, not a high-level symbolic processing language)
  ⇒ a **higher-level language** is useful
- garbage collection - even inside passes - eases development for (complex and circular) compiler data structures
  ⇒ Ggc is not enough : a **G-C working inside passes** is needed
- Extensions filter or search existing Gcc internal representations
  ⇒ **powerful pattern matching** (e.g. on *Gimple*, *Tree*-s, . . .) is needed

[33] Any development useful to all Gcc users should better go inside Gcc core!
[34] Most Gnu/Linux distributions don't even package Gcc branches or forks.

Embedding a scripting language is impossible

Many scripting or high-level languages [35] can be embedded in some other software: Lua, Ocaml, Python, Ruby, Perl, many Scheme-s, etc . . .

But in practice **this is not doable** for Gcc (we tried one month for Ocaml) :

- mixing two garbage collectors (the one in the language & Ggc) is error-prone
- Gcc has many existing **GTY**-ed types
- the Gcc API is huge, and still evolving
  (glue code for some scripting implementation would be obsolete before finished)
- since some of the API is low level (accessing fields in `struct`-s), glue code would have big overhead ⇒ performance issues
- Gcc has an ill-defined, non "functional" [e.g. with only true functions] or "object-oriented" API; e.g. iterating is not always thru functions and callbacks:

```
/* iterating on every gimple stmt inside a basic block bb */
for (gimple_stmt_iterator gsi = gsi_start_bb (bb);
     !gsi_end_p (gsi); gsi_next (&gsi)) {
  gimple stmt = gsi_stmt (gsi); /* handle stmt ...*/ }
```

[35] Pedantically, languages' *implementations* can be embedded!

Melt, a Domain Specific Language translated to C

Melt is a **DSL** translated to C in the **style required** by Gcc

- C code generators are usual inside Gcc
- the Melt-generated C code is designed to fit well into Gcc (and Ggc)
- mixing small chunks of C code with Melt is easy
- Melt contains linguistic devices to help Gcc-friendly C code generation
- generating C code eases integration into the evolving Gcc API

The Melt language itself is tuned to fit into Gcc
In particular, it handles both its own Melt values and existing Gcc stuff

The Melt translator is bootstrapped, and Melt extensions are loaded by the `melt.so` plugin

With Melt, Gcc **may generate *C* code** while running, compiles it[36] into a Melt binary `.so` module and `dlopen`-s that module.

[36] By invoking `make` from `melt.so` loaded by `cc1`; often that `make` will run another `gcc -fPIC`

Melt values vs Gcc stuff

Melt handles **first-citizen** Melt **values**:

- values **like many scripting languages have** (Scheme, Python, Ruby, Perl, even Ocaml . . .)
- Melt **values are dynamically typed**[37], organized in a lattice; **each Melt value has its discriminant** (e.g. its class if it is an object)
- you should prefer dealing with Melt values in your Melt code
- values have their **own garbage-collector** (above Ggc), invoked implicitly

But Melt can also handle ordinary Gcc **stuff**:

- stuff is usually any **`GTY`**-ed Gcc raw data, e.g. **`tree`**, **`gimple`**, **`edge`**, **`basic_block`** or even **`long`**
- stuff is **explicitly typed** in Melt code thru **c-type annotations** like **`:tree`**, **`:gimple`** etc.
- adding new ctypes is possible (some of the Melt runtime is generated)

[37] Because designing a type-system friendly with Gcc internals mean making a type theory of Gcc internals!

Things = (Melt Values) ∪ (Gcc Stuff)

things	Melt **values**	Gcc **stuff**
memory manager	Melt GC (implicit, as needed, even inside passes)	Ggc (explicit, between passes)
allocation	**quick**, in the birth zone	`ggc_alloc`, by various zones
GC technique	copying generational (old → ggc)	mark and sweep
GC time	$O(\lambda)$ $\lambda =$ size of young live objects	$O(\sigma)$ $\sigma =$ total memory size
typing	dynamic, with discriminant	static, **`GTY`** annotation
GC roots	**local and global** variables	**only global** data
GC suited for	many short-lived temporary values	quasi-permanent data
GC usage	in **generated** C **code**	in hand-written code
examples	lists, closures, hash-maps, boxed `tree`-s, objects ...	raw `tree` stuff, raw `gimple` ...

Melt garbage collection

- co-designed with the Melt language
- co-implemented with the Melt translator
- manage only Melt values
  all Gcc raw stuff is still handled by Ggc
- **copying generational Melt garbage collector** (for Melt values only):
  1. **values quickly allocated** in birth region
     (just by incrementing a pointer; a Melt GC is triggered when the birth region is full.)
  2. **handle** well very **temporary values** and **local variables**
  3. **minor Melt GC**: scan local values (in Melt call frames), copy and move them out of birth region into Ggc heap
  4. **full Melt GC** = minor GC + `ggc_collect ();` [38]
  5. all local pointers (local variables) are in Melt frames
  6. needs a write barrier (to handle old → young pointers)
  7. requires tedious C coding: call frames, barriers, **normalizing nested expressions** (`z = f(g(x),y)` → temporary `τ = g(x); z=f(τ, y);`)
  8. **well suited for *generated* C code**

[38] So Melt code can trigger Ggc collection even **inside** Gcc passes!

a first silly example of Melt code

Nothing meaningful, to give a **first taste of Melt language**:

```
;; -*- lisp -*- MELT code in firstfun.melt
(defun foo (x :tree t)
       (tuple x
              (make_tree discr_tree t)))
```

- comments start with *;* up to EOL; case is not meaningful: `defun` ≡ `deFUn`
- **Lisp-like syntax**: **(** *operator operands . . .* **)** so **parenthesis are always significant** in Melt `(f)` ≢ `f`, but in **C** `f()` ≢ `f` ≡ `(f)`
- `defun` is a "macro" for ***def***ining ***fun***ctions in Melt
- Melt is an **expression based language**: everything is an expression giving a result
- `foo` is here the name of the defined function
- `(x :tree t)` is a formal arguments list (of *two* formals `x` and `t`); the "ctype keyword" `:tree` qualifies next formals (here `t`) as raw Gcc `tree`-s **stuff**
- `tuple` is a "macro" to **construct a tuple** value - here made of 2 component values
- `make_tree` is a "**primitive**" operation, to **box** the raw tree stuff `t` **into a value**
- `discr_tree` is a "**predefined value**", a discriminant object for boxed tree values

generated C code from previous example

The [low level] C code, has **more than 680 lines** in generated `firstfun.c`, including

```
melt_ptr_t MELT_MODULE_VISIBILITY
meltrout_1_firstfun_FOO
 (meltclosure_ptr_t closp_,
  melt_ptr_t firstargp_,
  const melt_argdescr_cell_t xargdescr_[],
  union meltparam_un *xargtab_,
  const melt_argdescr_cell_t xresdescr_[],
  union meltparam_un *xrestab_)
{
  struct frame_meltrout_1_firstfun_FOO_st {
    int mcfr_nbvar;
#if ENABLE_CHECKING
    const char *mcfr_flocs;
#endif
    struct meltclosure_st *mcfr_clos;
    struct excepth_melt_st *mcfr_exh;
    struct callframe_melt_st *mcfr_prev;
    void *mcfr_varptr[5];
    tree loc_TREE__o0;
  }  *framptr_ = 0, meltfram__;
  memset (&meltfram__, 0, sizeof (meltfram__));
  meltfram__.mcfr_nbvar = 5;
  meltfram__.mcfr_clos = closp_;
  meltfram__.mcfr_prev
     = (struct callframe_melt_st *) melt_topframe;
  melt_topframe
    = (struct callframe_melt_st *) &meltfram__;
  MELT_LOCATION ("firstfun.melt:2:/ getarg");
#ifndef MELTGCC_NOLINENUMBERING
#line 2 "firstfun.melt" /**::getarg::**/
#endif /*MELTGCC_NOLINENUMBERING */
```

```
 /*_.X__V2*/ meltfptr[1] = (melt_ptr_t) firstargp_;
  if (xargdescr_[0] != MELTBPAR_TREE)
    goto lab_endgetargs;
 /*_?*/ meltfram__.loc_TREE__o0 = xargtab_[0].meltbp_tre
lab_endgetargs:;
 /*_.MAKE_TREE__V3*/ meltfptr[2] =
#ifndef MELTGCC_NOLINENUMBERING
#line 4 "firstfun.melt" /**::expr::**/
#endif /*MELTGCC_NOLINENUMBERING */
      (meltgc_new_tree
       ((meltobject_ptr_t) (( /*!DISCR_TREE */ meltfrout
        ( /*_?*/ meltfram__.loc_TREE__o0)));;
    {
      struct meltletrec_1_st {
        struct MELT_MULTIPLE_STRUCT (2) rtup_0__TUPLREC_
        long meltletrec_1_endgap;
      } *meltletrec_1_ptr = 0;
      meltletrec_1_ptr = (struct meltletrec_1_st *)
        meltgc_allocate (sizeof (struct meltletrec_1_st)
 /*_.TUPLREC___V5*/ meltfptr[4] =
        (void *) &meltletrec_1_ptr->rtup_0__TUPLREC__x1;
      meltletrec_1_ptr->rtup_0__TUPLREC__x1.discr =
        (meltobject_ptr_t) (((void *)
         (MELT_PREDEF (DISCR_MULTIPLE))));
      meltletrec_1_ptr->rtup_0__TUPLREC__x1.nbval = 2;
      ((meltmultiple_ptr_t) ( /*_.TUPLREC___V5*/ meltfpt
        (melt_ptr_t) ( /*_.X__V2*/ meltfptr[1]);
      ((meltmultiple_ptr_t) ( /*_.TUPLREC___V5*/ meltfpt
        (melt_ptr_t) ( /*_.MAKE_TREE__V3*/ meltfptr[2]);
      meltgc_touch ( /*_.TUPLREC___V5*/ meltfptr[4]);
     /*_.RETVAL___V1*/ meltfptr[0] = /*_.TUPLE___V4*/ me
```

“hello world” in Melt, a mix of Melt and *C* code

```
;; file helloworld.melt
(code_chunk helloworldchunk
   #{ /* our $HELLOWORLDCHUNK */ int i=0;
   $HELLOWORLDCHUNK#_label:
   printf("hello world from MELT %d\n", i);
   if (i++ < 3) goto $HELLOWORLDCHUNK#_label; }# )
```

- **code_chunk** is to Melt what **asm** is to *C* : for **inclusion** of chunks in the **generated** code (*C* for Melt, assembly for C or `gcc`);
  rarely useful, but we can't live without!
- **helloworldchunk** is the **state symbol**; it gets **uniquely expanded** [39] in the generated code (as a C identifier unique to the C file)
- **#{** and **}#** delimit **macro-strings**, lexed by Melt as a list of symbols (when prefixed by `$`) and strings: `#{A"$B#C"\n"}#` ≡ `("A\""  b  "C\"\\n")` [a 3-elements list, the 2nd is symbol **b**, others are strings]

[39] Like Gcc predefined macro ***__COUNTER__*** or Lisp's `gensym`

running our helloworld.melt program

Notice that it has no `defun` so don't define any Melt function.

It has one single expression, useful for its side-effects!

With the Melt **branch**:

```
gcc-melt -fmelt-mode=runfile \
    -fmelt-arg=helloworld.melt -c example1.c
```

With the Melt **plugin**:

```
gcc-4.7 -fplugin=melt -fplugin-arg-melt-mode=runfile \
     -fplugin-arg-melt-arg=helloworld.melt -c example1.c
```

Run as

```
cc1: note: MELT generated new file
      /tmp/GCCMeltTmpdir-1c5b3a95/helloworld.c
cc1: note: MELT has built module
      /tmp/GCCMeltTmpdir-1c5b3a95/helloworld.so in 0.416 sec.
hello world from MELT
hello world from MELT
hello world from MELT
hello world from MELT
cc1: note: MELT removed 3 temporary files
           from /tmp/GCCMeltTmpdir-1c5b3a95
```

How Melt is running

- Using Melt as plugin is the same as using the Melt branch: $\forall\alpha\forall\sigma$ **-fmelt-α=σ** in the Melt **branch** $\equiv$ **-fplugin-arg-melt-α=σ** with the `melt.so` **plugin**
- for **development, the Melt branch**[40] could be preferable (more checks and debugging features)
- Melt don't do anything more than Gcc without a **mode**
  - so without any mode, `gcc-melt` $\equiv$ `gcc-trunk`
  - use **-fmelt-mode=help** to get the list of modes
  - your Melt extension usually registers additional mode[s]
- **Melt is not a Gcc front-end**
  so you need to pass a *C* (or *C++*, ...) input file to `gcc-melt` or `gcc`
  often with `-c` **empty.c** or **-x c /dev/null**
  when asking Melt to translate your Melt file
- **some Melt modes run a `make`** to compile thru `gcc -fPIC` the generated *C* code; **most of the time is spent in** that `make` **compiling** the generated *C* code

[40]The trunk is often merged (weekly at least) into the Melt branch

Melt modes for translating `*.melt` files

(usually run on `empty.c`)

The name of the **`*.melt`** file is passed with **`-fmelt-arg=`*`filename`*`.melt`**
The **mode** μ passed with **`-fmelt-mode=`**μ

- **`runfile`** to **translate** into a *C* file, `make` the *`filename`*`.so` Melt module, load it, **then discard everything**.
- **`translatedebug`** to translate into a `.so` Melt module built with `gcc -fPIC -g`
- **`translatefile`** to translate into a `.c` generated *C* file
- **`translatetomodule`** to translate into a `.so` Melt module (keeping the `.c` file).

Sometimes, **several** *C* files ***`filename`*`.c`**, ***`filename`*`+01.c`**, ***`filename`*`+02.c`**, . . . are generated from your ***`filename`*`.melt`**

A single Melt module ***`filename`*`.so`** is generated, to be `dlopen`-ed by Melt you can pass **`-fmelt-extra=`**μ_1**`:`**μ_2 to also load your μ_1 & μ_2 modules

expansion of the **code_chunk** in generated *C*

389 lines of generated *C*, including comments, `#line`, empty lines, with:

```
 {
#ifndef MELTGCC_NOLINENUMBERING
#line 3
#endif
  int i=0; /* our HELLOWORLDCHUNK__1 */
     HELLOWORLDCHUNK__1_label: printf("hello world from MELT\n");
     if (i++ < 3) goto HELLOWORLDCHUNK__1_label; ;}
  ;
```

Notice the **unique expansion** **`HELLOWORLDCHUNK__1`** of the **state symbol** **`helloworldchunk`**

Expansion of code with holes given thru *macro-strings* is central in Melt

Why Melt generates so many *C* lines?

- **normalization** requires lots of temporaries
- **translation** to *C* is "straightforward" ☺
- the **generated *C* code is very low-level**!
- code for **forwarding local pointers** (for Melt copying GC) is generated
- most of the code is in the **initialization**:
  - the generated **`start_module_melt`** takes a parent environment and produces a new environment
  - uses hooks in the **`INITIAL_SYSTEM_DATA`** predefined value
  - creates a new environment (binding **exported** variables)
  - Melt don't generate any "data" : all the data is built by (sequential, boring, huge) code in **`start_module_melt`**
- the Melt language is higher-level than *C*
- ratio of 10-35 lines of generated *C* code for one line of Melt is not uncommon
- ⇒ the **bottleneck** is the **compilation by `gcc -fPIC`** thru `make` **of the generated *C* code**

Gcc internal representations

Gcc has several "inter-linked" representations:

- **Generic** and **Tree**-s in the front-ends
  (with language specific variants or extensions)
- **Gimple** and others in the middle-end
  - **Gimple** operands are **Tree**-s
  - Control Flow Graph **Edge**-s, **Basic Block**-s, **Gimple Seq**-ences
  - use-def chains
  - **Gimple/SSA** is a **Gimple** variant
- **RTL** and others in the back-end

A given representation is defined by many **`GTY`**-ed *C* types
(discriminated unions, "inheritance", ...)
`tree`, **`gimple`**, **`basic_block`**, **`gimple_seq`**, **`edge`** ... **are `typedef`-ed pointers**

Some representations have various roles
Tree both for declarations and for **Gimple** arguments
in `gcc-4.3` or before *Gimple*s were *Tree*s

Why a Lisp-y syntax for Melt

True reason: **I** [Basile] **am lazy** ☺, also

- Melt is bootstrapped
  - now Melt translator[41] is written in Melt
    `$GCCMELTSOURCE/gcc/`**`melt/warmelt-*.melt`**
    ⇒ the ***C* translation** of Melt translator is **in its *source* repository**[42]
    `$GCCMELTSOURCE/gcc/`**`melt/generated/warmelt-*.c`**
  - parts of the Melt runtime (G-C) are generated
    `$GCCMELTSOURCE/gcc/`**`melt/generated/meltrunsup*.[ch]`**
  - major dependency of Melt translator is Ggc[43]
- reading in `melt-runtime.c` Melt syntax is nearly trivial
- as in many Lisp-s or Scheme-s, most of the parsing work is done by **macro-expansion** ⇒ modular syntax (extensible by advanced users)
- **existing support for Lisp** (Emacs mode) works for Melt
- **familiar look** if you know **Emacs** Lisp, Scheme, Common Lisp, or Gcc **`.md`**

[41] Melt started as a Lisp program

[42] This is unlike other *C* generators inside Gcc

[43] The Melt translator almost don't care of `tree`-s or `gimple`-s

Why and how Melt is bootstrapped

- Melt **delivered** in both **original** `.melt` & **translated** `.c` forms
  gurus could `make upgrade-warmelt` to regenerate all generated code in source tree.
- at installation, Melt translates itself several times
  (most of installation time is spent in those [re]translations and in compiling them)
- $\Rightarrow$ the Melt translator is a good test case for Melt;
  it exercices its runtime and itself (and Gcc do likewise)
- historically, Melt translator written using less features than those newly implemented (e.g. pattern matching rarely used in translator)

main Melt traits [inspired by Lisp]

- **`let`** : define *sequential* **local bindings** (like **`let*`** in Scheme) and evaluate sub-expressions with them
  `letrec` : define co-**rec**ursive local constructive bindings
- **`if`** : simple **conditional expression** (like **`?:`** in *C*); **`when`**, **`unless`** sugar
  `cond` : complex **conditional expression** (with several conditions)
- **`instance`** : build dynamically a new Melt object
  `definstance` : define a static instance of some class
- **`defun`** : define a named function
  `lambda` : build dynamically an anonymous function closure
- **`match`** : for **pattern-matching**[44]
- **`setq`** : assignment
- **`forever`** : infinite loop, exited with **`exit`**
- **`return`** : return from a function
  may return several things at once (primary result should be a value)
- **`multicall`** : call with several results

[44] a huge generalization of **`switch`** in *C*

non Lisp-y features of Melt

Many linguistic devices to **decribe how to generate *C*** code

- **`code_chunk`** to include bits of *C*
- **`defprimitive`** to define primitive operations
- **`defciterator`** to define iterative constructs
- **`defcmatcher`** to define matching constructs

Values vs **stuff** :

- **c-type** like **`:tree`**, **`:long`** to annotate stuff (in formals, bindings, . . .) and **`:value`** to annotate values
- **`quote`**, with lexical convention **`'`**$\alpha \equiv$ **`(quote`** α**`)`**
  - **`(quote 2)`** $\equiv$ **`'2`** is a boxed constant integer (but `2` is a constant long thing)
  - **`(quote "ab")`** $\equiv$ **`'"ab"`** is a boxed constant string
  - **`(quote x)`** $\equiv$ **`'x`** is a constant symbol (instance of `class_symbol`)

  `quote` in Melt is different than **`quote`** in Lisp or Scheme.
  In Melt it makes constant boxed values, so `'2` $\not\equiv$ `2`

defining your mode and pass in Melt

code by Pierre Vittet in his GMWarn extension

```
(defun test_fopen_docmd (cmd moduldata)
    (let ( (test_fopen          ;a local binding!
            (instance class_gcc_gimple_pass
                      :named_name '"melt_test_fopen"
                      :gccpass_gate test_fopen_gate
                      :gccpass_exec test_fopen_exec
                      :gccpass_data (make_maptree discr_map_trees 1000)
                      :gccpass_properties_required ()
          )))      ;body of the let follows:
   (install_melt_gcc_pass test_fopen "after" "ssa" 0)
   (debug "test_fopen_mode installed test_fopen=" test_fopen)
   ;; return the pass to accept the mode
   (return test_fopen)))

(definstance test_fopen class_melt_mode
    :named_name '"test_fopen"
    :meltmode_help '"monitor that after each call to fopen, there is a tes
    :meltmode_fun test_fopen_docmd
)
(install_melt_mode test_fopen)
```

Gcc *Tree*-s

A central front-end and middle-end representation in Gcc:
in *C* the type **`tree`** (a pointer)
See files `$GCCSOURCE/gcc/`**`tree.{def,h,c}`**, and also `$GCCSOURCE/gcc/`**`c-family/c-common.def`** and other front-end dependent files `#include`-d from `$GCCBUILD/gcc/all-tree.def`

`tree.def` contains ≈ **190** definitions like

```
/* Contents are in TREE_INT_CST_LOW and TREE_INT_CST_HIGH fields,
   32 bits each, giving us a 64 bit constant capability.  INTEGER_CST
   nodes can be shared, and therefore should be considered read only.
   They should be copied, before setting a flag such as TREE_OVERFLOW.
   If an INTEGER_CST has TREE_OVERFLOW already set, it is known to be uniq
   INTEGER_CST nodes are created for the integral types, for pointer
   types and for vector and float types in some circumstances.  */
DEFTREECODE (INTEGER_CST, "integer_cst", tcc_constant, 0)
```

or

```
/* C's float and double.  Different floating types are distinguished
   by machine mode and by the TYPE_SIZE and the TYPE_PRECISION.  */
DEFTREECODE (REAL_TYPE, "real_type", tcc_type, 0)
```

Tree representation in *C*

tree.h contains

```
struct GTY(()) tree_base {
  ENUM_BITFIELD(tree_code) code : 16;
  unsigned side_effects_flag : 1;
  unsigned constant_flag : 1;
  // many other flags
};
struct GTY(()) tree_typed {
  struct tree_base base;
  tree type;
};
  // etc
union GTY ((ptr_alias (union lang_tree_node),
    desc ("tree_node_structure (&%h)"), variable_size)) tree_node {
  struct tree_base GTY ((tag ("TS_BASE"))) base;
  struct tree_typed GTY ((tag ("TS_TYPED"))) typed;
  // many other cases
  struct tree_target_option GTY ((tag ("TS_TARGET_OPTION"))) target_option
};
```

But `$GCCSOURCE/gcc/`**coretypes.h** has

```
typedef union tree_node *tree;
```

Gcc *Gimple*-s

Gimple-s represents instructions in Gcc
in *C* the type **`gimple`** (a pointer)
See files `$GCCSOURCE/gcc/`**`gimple.{def,h,c}`**

`gimple.def` contains **36** definitions **(14 are for OpenMP !)** like

```
/* GIMPLE_GOTO <TARGET> represents unconditional jumps.
   TARGET is a LABEL_DECL or an expression node for computed GOTOs.  */
DEFGSCODE(GIMPLE_GOTO, "gimple_goto", GSS_WITH_OPS)
```

or

```
/* GIMPLE_CALL <FN, LHS, ARG1, ..., ARGN[, CHAIN]> represents function
   calls.
   FN is the callee.  It must be accepted by is_gimple_call_addr.
   LHS is the operand where the return value from FN is stored.  It may
   be NULL.
   ARG1 ... ARGN are the arguments.  They must all be accepted by
   is_gimple_operand.
    CHAIN is the optional static chain link for nested functions.  */
DEFGSCODE(GIMPLE_CALL, "gimple_call", GSS_CALL)
```

Gimple assigns

```
/* GIMPLE_ASSIGN <SUBCODE, LHS, RHS1[, RHS2]> represents the assignment
   statement
   LHS = RHS1 SUBCODE RHS2.
   SUBCODE is the tree code for the expression computed by the RHS of the
   assignment.  It must be one of the tree codes accepted by
   get_gimple_rhs_class.  If LHS is not a gimple register according to
   is_gimple_reg, SUBCODE must be of class GIMPLE_SINGLE_RHS.
   LHS is the operand on the LHS of the assignment.  It must be a tree nod
   accepted by is_gimple_lvalue.
   RHS1 is the first operand on the RHS of the assignment.  It must alway
   present.  It must be a tree node accepted by is_gimple_val.
   RHS2 is the second operand on the RHS of the assignment.  It must be a
   node accepted by is_gimple_val.  This argument exists only if SUBCODE i
   of class GIMPLE_BINARY_RHS.  */
DEFGSCODE(GIMPLE_ASSIGN, "gimple_assign", GSS_WITH_MEM_OPS)
```

Gimple operands are *Tree*-s. For *Gimple/SSA*, the *Tree* is often a **SSA_NAME**

Gimple data in *C*

in `$GCCSOURCE/gcc/gimple.h`:

```
/* Data structure definitions for GIMPLE tuples.  NOTE: word markers
   are for 64 bit hosts.  */
struct GTY(()) gimple_statement_base {
  /* [ WORD 1 ] Main identifying code for a tuple.  */
  ENUM_BITFIELD(gimple_code) code : 8;
  // etc...
  /* Number of operands in this tuple.  */
  unsigned num_ops;
  /* [ WORD 3 ] Basic block holding this statement.  */
  struct basic_block_def *bb;
  /* [ WORD 4 ] Lexical block holding this statement.  */
  tree block; };
/* Base structure for tuples with operands.  */
struct GTY(()) gimple_statement_with_ops_base {
  /* [ WORD 1-4 ]  */
  struct gimple_statement_base gsbase;
  /* [ WORD 5-6 ] SSA operand vectors.  NOTE: It should be possible to
     amalgamate these vectors with the operand vector OP.  However,
     the SSA operand vectors are organized differently and contain
     more information (like immediate use chaining).  */
  struct def_optype_d GTY((skip (""))) *def_ops;
  struct use_optype_d GTY((skip (""))) *use_ops; };
```

inline accessors to *Gimple*

gimple.h also have many **inline functions**, like e.g.

```
/* Return the code for GIMPLE statement G.  crash if G is null */
static inline enum gimple_code gimple_code (const_gimple g)  {...}
/* Set the UID of statement. data for inside passes */
static inline void gimple_set_uid (gimple g, unsigned uid) {...}
/* Return the UID of statement. */
static inline unsigned gimple_uid (const_gimple g) {...}
/* Return true if GIMPLE statement G has register or memory operands. */
static inline bool gimple_has_ops (const_gimple g) {...}
/* Return the set of DEF operands for statement G. */
static inline struct def_optype_d *gimple_def_ops  (const_gimple g) {...}
/* Return operand I for statement GS. */
static inline tree gimple_op (const_gimple gs,  unsigned i) {...}
/* If a given GIMPLE_CALL's callee is a FUNCTION_DECL, return it.
   Otherwise return NULL. This function is analogous to get_callee_fndecl in tree
static inline tree gimple_call_fndecl (const_gimple gs)  {...}
/* Return the LHS of call statement GS. */
static inline tree gimple_call_lhs (const_gimple gs) {...}
```

There are also functions to **build or modify gimple**

control-flow related representations inside Gcc

- **gimple** are simple instructions
- **gimple_seq** are sequence of `gimple`-s
- **basic_block** are elementary blocks, containing a `gimple_seq` and connected to other basic blocks thru `edge`-s
- **edge**-s connect basic blocks (i.e. are jumps!)
- **loop**-s are for dealing with loops, knowing their basic block **headers** and **latches**
- the `struct` **control_flow_graph** packs entry and exit blocks and a vector of basic blocks for a function
- the `struct` **function** packs the `control_flow_graph` and the `gimple_seq` of the function body, etc ...
- `loop`-s are hierachically organized inside the `struct` **loops** (e.g. the **current_loops** global) for the current function.

NB: **not every representation** is **available** in every pass!

Basic Blocks in Gcc

coretypes.h has **typedef struct basic_block_def *basic_block;**

In $GCCSOURCE/gcc/**basic-block.h**

```
/* Basic block information indexed by block number.  */
struct GTY((chain_next ("%h.next_bb"), chain_prev("%h.prev_bb"))) basic_block_def
  /* The edges into and out of the block.  */
  VEC(edge,gc) *preds;
  VEC(edge,gc) *succs;  //etc ...
  /* Innermost loop containing the block.  */
  struct loop *loop_father;
  /* The dominance and postdominance information node.  */
  struct et_node * GTY ((skip (""))) dom[2];
  /* Previous and next blocks in the chain.  */
  struct basic_block_def *prev_bb;
  struct basic_block_def *next_bb;
  union basic_block_il_dependent {
      struct gimple_bb_info * GTY ((tag ("0"))) gimple;
      struct rtl_bb_info * GTY ((tag ("1"))) rtl;
    } GTY ((desc ("((%1.flags & BB_RTL) != 0)"))) il;
  // etc ....
  /* Various flags.  See BB_* below.  */
  int flags;
};
```

gimple_bb_info & control_flow_graph

Also in **basic-block.h**

```
struct GTY(()) gimple_bb_info {
  /* Sequence of statements in this block.  */
  gimple_seq seq;
  /* PHI nodes for this block.  */
  gimple_seq phi_nodes;
};

/* A structure to group all the per-function control flow graph data. */
struct GTY(()) control_flow_graph {
  /* Block pointers for the exit and entry of a function.
     These are always the head and tail of the basic block list.  */
  basic_block x_entry_block_ptr;
  basic_block x_exit_block_ptr;
  /* Index by basic block number, get basic block struct info.  */
  VEC(basic_block,gc) *x_basic_block_info;
  /* Number of basic blocks in this flow graph.  */
  int x_n_basic_blocks;
  /* Number of edges in this flow graph.  */
  int x_n_edges;
  // etc ...
};
```

Control Flow Graph and `loop`-s in Gcc

In `$GCCSOURCE/gcc/`**`cfgloop.h`**

```
/* Description of the loop exit.  */
struct GTY (()) loop_exit {
  /* The exit edge.  */
  struct edge_def *e;
  /* Previous and next exit in the list of the exits of the loop.  */
  struct loop_exit *prev;      struct loop_exit *next;
  /* Next element in the list of loops from that E exits.  */
  struct loop_exit *next_e;  };
typedef struct loop *loop_p;
/* Structure to hold information for each natural loop.  */
struct GTY ((chain_next ("%h.next"))) loop {
  /* Index into loops array.  */
  int num;
  /* Number of loop insns.  */
  unsigned ninsns;
  /* Basic block of loop header.  */
  struct basic_block_def *header;
  /* Basic block of loop latch.  */
  struct basic_block_def *latch;
    // etc ...
  /* True if the loop can be parallel.  */
  bool can_be_parallel;
  /* Head of the cyclic list of the exits of the loop.  */
  struct loop_exit *exits;
};
```

Caveats on Gcc internal representations

- in principle, **they are not stable** (could change in `4.7` or next)
- in practice, **changing central representations** (like `gimple` or `tree`) is very **difficult** :
  - Gcc gurus (and users?) care about compilation time
  - Gcc people could "fight" for some bits
  - changing them is very costly: ⇒ need to patch every pass
  - you need to convince the whole Gcc community to enhance them
  - some Gcc heroes could change them
- **extensions or plugins cannot add extra** data **fields** (into `tree`-s, `gimple`-s[45] or `basic_block`-s, ...)
  ⇒ use other data (e.g. associative hash tables) to link your data to them

[45] *Gimple*-s have *uid*-s but they are only for inside passes!

Handling GCC stuff with MELT

Gcc raw stuff is handled by Melt c-types like **`:gimple_seq`** or **`:edge`**

- raw stuff can be passed as formal arguments or given as secondary results
- Melt functions
  - **first argument[46] should be a value**
  - **first result is a value**
- raw stuff have boxed values counterpart
- raw stuff have hash-maps values (to associate a non-nil Melt value to a `tree`, a `gimple` etc)
- **primitive** operations can handle stuff or values
- **c-iterators** can iterate inside stuff or values

[46] i.e. the reciever, when sending a message in Melt

Primitives in Melt

Primitive operations have arbitrary (but fixed) signature, and give one result (which could be **:void**).

used e.g. in Melt where `body` is some **:basic_block** stuff
(code by Jérémie Salvucci from `xtramelt-c-generator.melt`)

```
(let ( (:gimple_seq instructions  (gimple_seq_of_basic_block body)) )
  ;; do something with  instructions
)
```

(`gimple_seq_of_basic_block` takes a `:basic_block` stuff & gives a `:gimple_seq` stuff)

Primitives are defined thru **defprimitive** by macro-strings, e.g. in
`$GCCMELTSOURCE/gcc/melt/xtramelt-ana-base.melt`

```
(defprimitive gimple_seq_of_basic_block (:basic_block bb) :gimple_seq
  #{(($BB)?bb_seq(($BB)):NULL)}#)
```

(always test for 0 or null, since Melt data is cleared initially)
Likewise, arithmetic on raw **:long** stuff is defined (in `warmelt-first.melt`):

```
(defprimitive +i (:long a b) :long
  :doc #{Integer binary addition of $a and $b.}#
  #{(($A) + ($B))}#)
```

(no boxed arithmetic primitive yet in Melt)

c-iterators in Melt

C-iterators describe how to iterate, by generation of `for`-like constructs, with

- **input** arguments - for parameterizing the iteration
- **local** formals - giving locals changing on each iteration

So if `bb` is some Melt **`:basic_block`** stuff, we can iterate on its contained `:gimple`-s using

```
(eachgimple_in_basicblock
        (bb)     ;; input arguments
        (:gimple g)     ;; local formals
        (debug "our g=" g) ;; do something with g
)
```

The definition of a **c-iterator**, in a **`defciterator`**, uses a **state symbol** (like in **`code_chunk`**-s) and two “before” and “after” macro-strings, expanded in the head and the tail of the generated *C* loop.

Example of **defciterator**

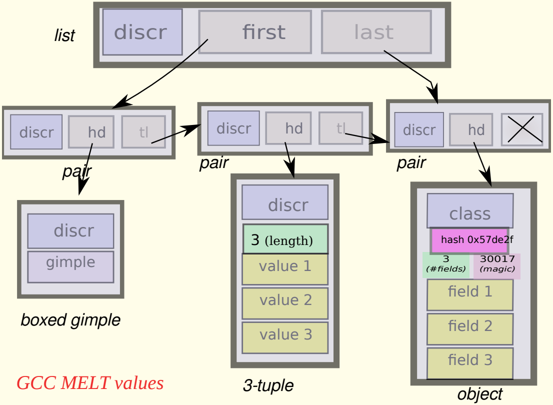
in `xtramelt-ana-base.melt`

```
(defciterator eachgimple_in_basicblock
  (:basic_block bb)          ;start formals
  eachgimpbb                 ;state symbol
  (:gimple g)                ;local formals
  ;;; before expansion
  #{   /* start $EACHGIMPBB */
   gimple_stmt_iterator gsi_$EACHGIMPBB;
   if ($BB)
     for (gsi_$eachgimpbb = gsi_start_bb ($BB);
          !gsi_end_p (gsi_$EACHGIMPBB);
          gsi_next (&gsi_$EACHGIMPBB)) {
       $G = gsi_stmt (gsi_$EACHGIMPBB);
  }#
  ;;; after expansion
  #{ } /* end $EACHGIMPBB */ }#
)
```

(most iterations in Gcc fit into *c-iterators*; because few are callbacks based)

values in Melt

Each value starts with an immutable [often predefined] **discriminant** (for a Melt object value, the discriminant is its class).



GCC MELT values

Melt copying generational garbage collector manages [only] values (it copies live Melt values into Ggc heap).

values taxonomy

- classical almost Scheme-like (or Python-like) values:
  1. the **nil** value `()` - it is the only **false** value (unlike Scheme)
  2. **boxed integers**, e.g. `'2`; or **boxed strings**, e.g. `'"ab"`
  3. **symbols** (objects of `class_symbol`), e.g. `'x`
  4. **closures**, i.e. functions [only **values** can be **closed** by `lambda` or `defun`] (also [internal to closures] **routines** containing constants) e.g. `(lambda (f :tree t) (f y t))` has closed `y`
  5. **pairs** (rarely used alone)
- **boxed stuff**, e.g. **boxed gimples** or **boxed basic blocks**, etc ...
- **lists** of pairs (unlike Scheme, they know their first and last pairs)
- **tuples** $\equiv$ fixed array of immutable components
- **associative homogenous hash-maps**, keyed by either
  - non-nil Gcc raw stuff like `:tree`-s, `:gimple`-s ... **(all keys of same type)**, or
  - Melt objects

  with each such key associated to a non-nil Melt value
- **objects** - (their discriminant is their class)

lattice of discriminants

- Each value has its immutable discrimnant.
- Every discriminant is an object of `class_discriminant` (or a subclass)
- Classes are objects of `class_class`
  Their fields are reified as instances of `class_field`
- The nil value (represented by the `NULL` pointer in generated *C* code) has `discr_null_reciever` as its discriminant.
- each discriminant has a parent discriminant (the super-class for classes)
- the top-most discriminant is `discr_any_reciever`
  (usable for catch-all methods)
- discriminants are used by garbage collectors (both Melt and Ggc!)
- discriminants are used for Melt **message sending**:
  - each message send has a selector σ & a reciever ρ, i.e. **(**σ ρ **...)**
  - selectors are objects of `class_selector` defined with `defselector`
  - recievers can be any Melt value (even nil)
  - discriminants have a `:disc_methodict` field - an object-map associating selectors to methods (closures); and their `:disc_super`

C-type example: ctype_tree

Our **c-types** are described by Melt [predefined] objects, e.g.

```
;; the C type for gcc trees
(definstance ctype_tree class_ctype_gty
  :doc #{The $CTYPE_TREE is the c-type
of raw GCC tree stuff. See also
$DISCR_TREE. Keyword is :tree.}#
  :predef CTYPE_TREE
  :named_name  '"CTYPE_TREE"
  :ctype_keyword ':tree
  :ctype_cname  '"tree"
  :ctype_parchar '"MELTBPAR_TREE"
  :ctype_parstring '"MELTBPARSTR_TREE"
  :ctype_argfield '"meltbp_tree"
  :ctype_resfield '"meltbp_treeptr"
  :ctype_marker '"gt_ggc_mx_tree_node"
;; GTY ctype
  :ctypg_boxedmagic '"MELTOBMAG_TREE"
  :ctypg_mapmagic '"MELTOBMAG_MAPTREES"
  :ctypg_boxedstruct '"melttree_st"
  :ctypg_boxedunimemb '"u_tree"
  :ctypg_entrystruct '"entrytreemelt_st"
  :ctypg_mapstruct '"meltmaptrees_st"
  :ctypg_boxdiscr  discr_tree
  :ctypg_mapdiscr  discr_map_trees
  :ctypg_mapunimemb    '"u_maptrees"
  :ctypg_boxfun        '"meltgc_new_tree"
  :ctypg_unboxfun      '"melt_tree_content
  :ctypg_updateboxfun  '"meltgc_tree_updat
  :ctypg_newmapfun     '"meltgc_new_maptre
  :ctypg_mapgetfun     '"melt_get_maptrees
  :ctypg_mapputfun     '"melt_put_maptrees
  :ctypg_mapremovefun  '"melt_remove_maptr
  :ctypg_mapcountfun   '"melt_count_maptre
  :ctypg_mapsizefun    '"melt_size_maptree
  :ctypg_mapnattfun    '"melt_nthattr_mapt
  :ctypg_mapnvalfun    '"melt_nthval_maptr
  )

(install_ctype_descr
      ctype_tree "GCC tree pointer")
```

The strings are the names of **generated run-time support** routines (or types, enum-s, fields . . .) in `$GCCMELTSOURCE/gcc/melt/generated/`**`meltrunsup*.[ch]`**

Melt objects and classes

Melt objects have a single class (class hierarchy rooted at **class_root**)
Example of class definition in `warmelt-debug.melt`:

```
;; class for debug information (used for debug_msg & dbgout* stuff)
(defclass class_debug_information
  :super class_root
  :fields (dbgi_out dbgi_occmap dbgi_maxdepth)
  :doc #{The $CLASS_DEBUG_INFORMATION is for debug information output,
e.g. $DEBUG_MSG macro.  The produced output or buffer is $DBGI_OUT,
the occurrence map is $DBGI_OCCMAP, used to avoid outputting twice the
same object. The boxed maximal depth is $DBGI_MAXDEPTH.}#
)
```

We use it in code like

```
   (let ( (dbgi (instance class_debug_information
                      :dbgi_out out
                      :dbgi_occmap occmap
                      :dbgi_maxdepth boxedmaxdepth))
         (:long framdepth (the_framedepth))
        )
     (add2out_strconst out "!!!!****####")
     ;; etc
   )
```

Melt fields and objects

Melt **field names are globally unique**

- ⇒ `(get_field :dbgi_out dbgi)` is translated to **safe code**:
  1. testing that indeed `dbgi` is instance of `class_debug_information`, then
  2. extracting its `dbgi_out` field.
- (⇒ never use **unsafe_get_field**, or your code could crash)
- Likewise, `put_fields` is safe
- (⇒ never use **unsafe_put_fields**)
- **convention:** all proper field names of a class share a common prefix
- no visibility restriction on fields
  (except module-wise, on "private" classes not passed to `export_class`)

Classes are conventionally named `class_`⋆

Methods are dynamically installable on any discriminant, using
`(install_method` ***discriminant selector method*****)**

About pattern matching

You already used it, e.g.

- in regular expressions for substitution with `sed`
- in XSLT or Prolog (or expert systems rules with variables, or formal symbolic computing)
- in Ocaml, Haskell, Scala

A tiny calculator in Ocaml:

```
(*discriminated unions [sum type], with cartesian products*)
type expr_t =  Num  of  int
            |  Add  of  expr_t * expr_t
            |  Mul  of  expr_t * expr_t ;;
(*recursively compute an expression thru pattern matching*)
let rec compute e = match e with
    Num x  →  x
  | Add (a,b)  →  a + b
 (*disjunctive pattern with joker _ and constant sub-patterns::*)
  | Mul (_,Num 0)  |  Mul (Num 0,_)   →  0
  | Mul (a,b)  →  a * b ;;
(*inferred type: compute : expr_t → int *)
```

Then `compute (Add (Num 1, Mul (Num 2, Num 3)))` ⇒ 7

Using pattern matching in your Melt code

code by Pierre Vittet

```
(defun detect_cond_with_null (grdata :gimple g)
  (match g ;; the matched thing
        ( ?(gimple_cond_notequal ?lhs
                                 ?(tree_integer_cst 0))
          (make_tree discr_tree lhs))
        ( ?(gimple_cond_equal ?lhs
                              ?(tree_integer_cst 0))
          (make_tree discr_tree lhs))
        ( ?_
          (make_tree discr_tree (null_tree)))))
```

- lexical shortcut: **?**π $\equiv$ **(question** π**)**, much like **'**ϵ $\equiv$ **(quote** ϵ**)**
- **patterns are major syntactic constructs** (like expressions or bindings are; parsed with *pattern macros* or "patmacros"), first in matching clauses
- **?_** is the **joker pattern**, and **?lhs** is a **pattern variable** (local to its clause)
- most **patterns are nested**, made with **matchers**, e.g. **gimple_cond_notequal** or **tree_integer_const**

What **match** does?

- syntax is **(match** ϵ $\kappa_1 \ldots \kappa_n$ **)** with ϵ an expression giving μ and κ_j are matching clauses considered in sequence
- the `match` expression returns a result (some thing, perhaps **:void**)
- it is made of matching clauses **(** π_i $\epsilon_{i,1} \ldots \epsilon_{i,n_i}$ η_i **)**, each starting with a pattern[47] π_i followed by sub-expressions $\epsilon_{i,j}$ ending with η_i
- it matches (or filters) some thing μ
- **pattern variables** are **local** to their clause, and **initially cleared**
- when pattern π_i matches μ the expressions $\epsilon_{i,j}$ of clause *i* are executed in sequence, with the pattern variables inside π_i locally bound. The last sub-expression η_i of the match clause gives the result of the entire `match` (and all η_i should have a common c-type, or else **:void**)
- if no clause matches -this is bad taste, usually last clause has the **?_** joker pattern-, the result is cleared
- a pattern π_i can **match** the thing μ or **fail**

[47] expressions, e.g. constant litterals, are degenerate patterns!

pattern matching rules

rules for matching of pattern π against thing μ:

- the **joker pattern `?_` always match**
- an **expression** (e.g. a constant) ϵ (giving μ') matches μ **iff** `(`μ' `==` μ`)` in *C* parlance
- a **pattern variable** like **`?x`** matches if
  - `x` was unbound; then it is **bound** (locally to the clause) to μ
  - or else `x` was already bound to some μ' and `(`μ' `==` μ`)` ***[non-linear patterns]***
  - otherwise (`x` was bound to a different thing), the pattern variable `?x` match fails
- a **matcher pattern** `?(`m $\eta_1 \ldots \eta_n$ $\pi'_1 \ldots \pi'_p$`)` with $n \geq 0$ input argument sub-expressions η_i and $p \geq 0$ sub-patterns π'_j
  - the matcher m does a **test** using results ρ_i of η_i;
  - if the test succeeds, data are extracted in the **fill** step and each should match its π'_j
  - otherwise (the test fails, so) the match fails
- an **instance pattern** `?(`**`instance`** κ `:`ϕ_1 π'_1 ... `:`ϕ_n π'_n`)` matches iff μ is an object of class κ (or a sub-class) with each field ϕ_i matching its sub-pattern π'_i

control patterns

We have controlling patterns

- **conjonctive pattern** `?(and` $\pi_1 \ldots \pi_n$`)` matches μ iff π_1 matches μ and then π_2 matches μ ...
- **disjonctive pattern** `?(or` $\pi_1 \ldots \pi_n$`)` matches μ iff π_1 matches μ or else π_2 matches μ ...

Pattern variables are initially cleared, so `(match 1 (?(or ?x ?y) y))` gives `0` (as a `:long` stuff)

(other control patterns would be nice, e.g. backtracking patterns)

matchers

Two kinds of matchers:

1. **c-matchers** giving the *test* and the *fill* code thru expanded macro-strings

```
(defcmatcher gimple_cond_equal
  (:gimple gc) ;; matched thing μ
  (:tree lhs :tree rhs) ;; subpatterns putput
  gce ;; state symbol
  ;; test expansion:
  #{($GC &&
        gimple_code ($GC) == GIMPLE_COND &&
        gimple_cond_code ($GC) == EQ_EXPR)
  }#
  ;; fill expansion:
  #{ $LHS = gimple_cond_lhs ($GC);
       $RHS = gimple_cond_rhs ($GC);
  }#)
```

2. **fun-matchers** give test and fill steps thru a Melt function returning secondary results

Recent MELT improvements

Many bug fixes

- 0.9.3 (january 2012) and earlier in late 2011
  - **`define`** macro à la Scheme
  - cloning of values : `(`**`clone_with_discriminant`** *`old-val new-discr`*`)` whose implementation is generated
  - debugging closure with `(clone_with_discriminant (lambda ...) discr_debug_closure)`
  - walking SSA use-def chains
  - much more GCC plugin hooks interfaced to MELT
  - more MELT runtime code generated
- MELT 0.9.4 (march 2012)
  - **`cheader`** macro to emit header C-code, e.g. `(cheader #{#include <readline/readline.h>}#)`
  - all hash maps have some auxiliary data value
  - all generating devices emit code in a never-called syntax checking *C* function, to catch errors in macro-strings

Recent MELT improvements (2)

Many bug fixes

- MELT 0.9.5 (april 2012)
  - `$(sub s-epxr)` and `$[seq s-expr]` syntax in macro-strings
  - asynchronous input channels with `SIGIO` signal;
    signal handling in MELT at safe points (MELT applications, iterations...)
  - emitted *C* code is *C++* compatible (since second-stage `gcc-4.7` is compiled by `g++`)
  - much more c-matchers and primitives for GCC stuff
- MELT 0.9.6 (to be released end of may 2012)
  - signal support for `SIGIO`,`SIGALRM`,`SIGCHLD` -only in MELT code;
    centisecond real-time clock and timers
  - GTKmm probe communicating with MELT
  - even more c-matchers, primitives, functions for GCC stuff
  - less brittle installation
  - ?? variadic diagnostic functions for warning or error report
  - ?? support for using external libraries from MELT extension

known MELT weaknesses [corrections are worked upon]

1. pattern matching translation is weak[48]
   (a new pattern translator is nearly completed)
2. Melt passes can be slow
   - better and faster Melt application
   - memoization in message sends
   - optimization of Melt G-C invocations and Ggc invocations
3. variadic functions exist, but not enough used (e.g. for error and warning reports)
4. dump support exist, but not well used
5. a probe process: asynchronous communication with a GTK probe
6. OpenMP specific Gimple not yet supported
7. not all Tree-s are supported yet
8. lack of real LTO support

[48] Sometimes crashing the Melt translator ☹

Exercice

Code a Melt pass counting calls to a given function with null argument ☺